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A Case for the Five Year Curriculum

By FORD L. WILKINSON, JR.
Dean, Speed Scientific School, University of Louisville

Dean Grinter's very able article "Engineering Education Approaches a Crossroads," appearing in the January JOURNAL, merits published discussion. Having waited two months for those better qualified to take issue with Dean Grinter, the author puts temerity to one side and requests permission to place before the JOURNAL's readers some arguments, not in contradiction to the philosophy so ably pronounced in the subject article, but in support of a plan of engineering education that would more nearly achieve the objectives enunciated therein.

It seems that in the process of upholding the present time limit of four years of formal academic work, Dean Grinter has failed to recognize that the motives of those faculties accepting the five year curriculum are not, as he supposes, the result of "the enthusiasm of the moment for professionalizing engineering education." While the author cannot speak for those faculties, other than his own, and perhaps not for all of them, who have approved an extension of their curricula, he believes that he can safely say that such is farthest from their thoughts. Their motivation is completely the reverse.

Dr. Hotchkiss, President-emeritus of Rensselaer Polytechnic Institute, in addressing a meeting of the American Institute of Consulting Engineers, several years ago had this to say: "I believe that a man should be credited with culture when he has four attributes: when he is able to see in their proper perspective the factors of the problems before him; when he is able to have a true sense of the relative values of men and of things; when he is able to distinguish the true from the false; and fourth, a summary of all, when he has those attributes of a well-balanced mind which enable him to live intelligently in his environment."

Let us then attribute to those faculties who have adopted the five year undergraduate curriculum their belief that only by a very careful and judicious extension of the undergraduate curriculum in engineering may they accomplish the purpose of providing adequate opportunity for students in engineering school to acquire sufficient basic education to enable them eventually to "live intelligently" in their environment.

If, as Dean Grinter states: "Most teachers appear to feel that the majority of our graduates have reached an educational plateau and that little would be accomplished by keeping them in college for another year," we have certainly failed in creating a thirst and determination on the part of our students for culture as described by Dr. Hotchkiss. This is the same as saying that those students who aspire to educate themselves for the ever-expanding environment of the engineer have no capacity for the task.

It is believed that, even though undergraduate engineering college education should not be professionalized in the sense of placing undue emphasis on specialization, engineering schools have definite responsibilities to the engineering profession. Those responsibilities may be summed up as: (1) rigid selection of men for entrance to the profession, (2) to promote greater versatility through thorough instruction in fundamentals and practices, (3) to inculcate in students a high degree of ethical standards, (4) to assist in broadening knowledge and experience of the students in an environment which is expanding rapidly.

Although engineering schools are not professional schools in the same manner as are law and medical schools, they are the main avenue to the engineering profession and it is essential that they assume the responsibilities imposed upon them by this fact. These responsibilities cannot be discharged by permitting the almost unlimited freedom of election exemplified in many colleges of liberal arts. The requirements of these colleges are relatively simple. They establish certain "areas" of study and grant degrees upon the successful completion of a minimum number of credit hours in certain prescribed "areas." An examination of the offerings of the average college of liberal arts shows that the fundamental courses in science and the arts are not educational disciplines but, for the most part, generalizations or "surveys." By the term "educational discipline" is meant a manner of teaching subject matter that will give to the student useful and specific knowledge upon which he may build and develop.

These fundamentals, often loosely taught, do not prepare adequately for the pursuit of the liberal arts student's major study of the upper class years. In these major studies are perhaps a higher degree of specialization than in any graduate curriculum. The major in history may elect to concentrate on the Roman Empire, or the major in English on the works of some obscure author who was the subject of some professor's graduate thesis, thus making an excuse for the study of his works to be included in the curriculum.

It is contended here that this practice as carried out by too many colleges of liberal arts tends, because of its lack of educational discipline, to promote loose thinking to a far greater extent than do the professional schools. The latter, at least, through the very seriousness of their fixed and objective curricula, direct the student in a search for the truth.

All of this is not presented in adverse argument to the precepts presented so ably by Dean Grinter. The educational process as outlined by him is a condemnation of the preparation of the average liberal arts student. It may be interpreted as saying that the colleges of liberal arts, with their loose elective systems, do not appeal to the wide awake, intelligent young man who is seeking a "broad education that fortunately provides a reasonable earning capacity in our world today." Therefore, let us in the engineering schools do those things for him that the liberal arts college should do and does not. All well and good, but does such an educational program discharge the responsibilities that the engineering school has to the profession of engineering? We must do all of this and more.

In approving a five year curriculum the faculty of the school with which the author is associated made a critic

analysis of their educational program and came to these conclusions about it:

1. That the four year curriculum did not offer sufficient opportunity to permit offerings in those fields concerned with the relation of engineers with their environment.

2. Because of the time element in the four year curriculum our offerings in scientific fundamentals have been sacrificed for specialized courses in each of the four fields of engineering in which degrees are granted.

3. The result of the above has been to limit the versatility of the graduate in his usefulness to industry and business, and has so narrowed his educational interests that he may lack the necessary intellectual balance so necessary for effective citizenship.

The five year program was not adopted as an automatic cure-all for these educational deficiencies. The faculty very earnestly has set about to design a curriculum with definite checks placed upon specialization or as it might be called "professionalization." In addition, they have recognized that perhaps the greatest benefits of scientific and engineering study are obtained because of the controls they exercise upon the student. Therefore, they have kept before them the increasing demands and need for versatility, creativeness, and understanding in the engineering graduate.

The precepts laid down by the faculty as directives to the curriculum designers may be briefly outlined as follows:

1. The curriculum offerings outside the fields of science and engineering should extend throughout the five years of the students' residence. Furthermore, they should permit a reasonable degree of election; but these electives should not be courses admitted to the curriculum simply because of expediency. They should be objective in character and designed and taught to permit the analytical approach.

2. In the offerings in scientific and engineering fundamentals, the time devoted to these subjects should be spent in broadening their usefulness and directed toward an increase in the thoroughness with which they are taught. Extension of the offerings in certain sciences is encouraged. Mainly, there shall be an agreement on those fundamental sciences that are essential to the practice of engineering in all its branches and these should be taught without restrictions as to their applications.

3. There shall be no increase in the degree of specialization in the four branches of engineering in which the bachelor's degree is granted. The curriculum extension shall not be used as a means of bringing graduate study into the undergraduate curriculum.

As evidence that the faculty of a "leading state university," probably the one referred to by Dean Grinter, is similarly motivated the following statement from the Chairman of a Faculty Committee to the Dean is quoted:

"The Committee, therefore, arrived at the following general conclusions:

"(1) That while we are in no position to become complacent about our technical educational program, nevertheless our main problem today is to broaden our engineering education program to give our students an opportunity to broaden themselves so that they may develop greater effectiveness in the areas in which they are now weak.

"(2) Based on the preceding, the Committee arrived at the conclusion that the technical education of our engineers dare not be decreased in quantity and that the

necessary broadening cannot be done within the limits of a four year educational program.

"The Committee recommended a five year educational program with a ribbon of broadening subjects extending throughout (the five years). . . .

". . . It should be stated that the revamping of our entire program has given us the opportunity to revamp and improve our technical program. Some of us are convinced that the technical part of our educational program will be materially improved, first, by re-study and re-arrangement, and second, by the fact that the men in the fifth year will have an added degree of maturity and broader background educationally."

Thus it may be said that at least these two faculties have substantially the same objectives for their new programs of engineering education. It remains to be seen whether in the application they achieve the results desired, which may be briefly defined as encouraging the development of culture, as defined by Dr. Hotchkiss, in the engineering graduate. This does not mean that the engineering graduate is today uncultured, but it is to say that the extension of the engineering curriculum to five years offers the best opportunity to develop that culture in the engineering graduate and, at the same time, provides greater opportunity for the engineering school to meet its responsibilities to the engineering profession.

Instruction in Professional Qualities*

By N. W. DOUGHERTY

Dean of Engineering, The University of Tennessee

To teach professional qualities they must be recognized and studied. More than one list has been suggested. For the purposes of this paper we will assume the following as desirable qualities and as distinguishing characteristics of professional practitioners: A body of technical knowledge; An educational process; A service motive; A relation of confidence; Individual responsibility and group activities; Technical and professional organizations; Codes of conduct; Legal status; Exchange of technical knowledge.

Engineers have accepted the educational process as a part of the preparation for practice. They have organized themselves for the study of their educational activity and they have further organized to increase their technical abilities. The first two items therefore, have become a part of our regular professional procedures.

To have a profession there must be pride in ancestry and hope for posterity. No great organization came from nowhere, and to live it must have hope that it is going somewhere. Engineering as a profession is just beginning to come of age, yet it has a long history of accomplishments reaching from the shadows of the pyramids to modern industry. Through the centuries is marked a path which our forebears have followed; they have left "footprints on the sands of time."

As we grow professionally we must make a readable record of the achievements of engineers who have gone before and teach it to the practitioners of tomorrow. No other work would add to our professional consciousness and stimulate us more to further achievement. Possibly some one in this room, or some one of your students, will be the person to tell the story of achievement which began with the dawn of history and has continued with increasing tempo until this day.

Not only should some one record the achievements of engineers as a group, but he, and others, should write about the great men who have made our calling famous. Another Samuel Smiles should write of the men of today and yesterday, recording, for our generation and generations to come, the achievements of men who have builded the railroads, established industry, developed communications, and transmuted materials. Individual names should be recognized in a style of Elbert Hubbard in order that all who will may read.

A history and a tradition is not all. There must be a future which holds promise. Few are willing to become prophets of the new age now being born. All realize that the engineer must play a difficult and important

*Presented at the 52nd annual meeting, S.P.E.E. (Sections and Branches), Cincinnati, June 22–25, 1944.

part in it. Let us dream before our students about the great things of the future, that they may go from the classroom knowing that there is a place in the new world for them. These things can be taught by men of vision and only such men should be the teachers of the future.

Engineers are distinguished from other professionals by their method and technique and by the kinds of services they perform. By the study of technology they acquire the method and technique. Daily they solve with varying skill, the problems which presage their engineering activity. Good teaching will search for problems which simulate engineering practice and which develop the scientific method.

It is a paradox that science is often taught by those who know little or no science. By rote they teach that a law is true and on good authority, and they give no reason why. This is not scientific. To understand science and its method the student must be made to know that a law is true because all the evidence points to its truth. He does not remember its wording but he knows its truth. All roads may lead to Rome, but what is the meaning of the statement and what were the circumstances of its utterance? Teach the student to read in search of answers to questions and not to accept glib statements because they are in print.

We cannot live the experience of the race over in every class, but we can teach students to approach their tasks with a questioning mind and we can develop in them a spirit which will not believe without being persuaded. In every class the engineering instructor should consciously strive to develop the engineering method and technique. The students should be able to know when their solutions are correct and they should be able to develop methods of proving their every result.

The psalmist said "get understanding" and above all "get wisdom." To know that the result is correct the student must have an understanding of the problem and he must understand the solution. His judgments improve with experience in practical applications.

President Wickenden has preached the doctrine of the second mile. Its acceptance must be one of the first tenets of the professional man. Society has conspired to place him in a position where he alone knows what to do and again he, or his fellows, must judge whether he has acted with requisite knowledge and skill. This relation of confidence to the public and the client places a professional responsibility on the practitioner. Bearing this responsibility he can do no less than his very best. If it takes services not required in the bond, the services must be rendered in order that the job may be well done. Here is required a kind of work not fostered by "time and a half for overtime"; it is a kind of service that only a "servant of the people can render."

Some years ago Vannevar Bush developed the thesis that all professional men are direct descendants of the old medicine man who held his position of esteem in the tribe because of his service to the people. Lawyers, doctors, ministers, teachers, and engineers are not paid by the hour or even by the job; they are paid, in part at least, by the knowledge that they have served well. This may sound like Puritanism in this modern day, but it is the way professional men will earn the esteem

of their fellows and the confidence of the people.

An attitude of service may be difficult to transmit to students. It will not be hard to tell the story, but service may be a very elusive thing to teach. Surely we can foster the attitude and spirit by requiring the best possible performance of each assignment and exercise. Sloppiness and skimping have no place in the training of the engineer. Early in his career the student must learn that the best is worth doing for the sake of doing it.

To further understand professional responsibility the young engineer must know the relation of the practitioner to the client and the relation of the professional man to the public. By the laws of the land, professionals are given certain rights and privileges which are vouchsafed because of the nature of their work. Public health and public safety are often in their hands and always the public weal depends upon their actions. Since they must determine the solution of the problems of society and then be the judges of the rightness of their own acts, they are placed in a peculiar position of confidence to clients and to the public.

Group consciousness is essential to group nurture and maturity. For the professions groups are formed to further the knowledge of their work and to give professional aid to individual practitioners. No one engineer can build a profession; no one practitioner can build a railroad or an industry. Exchange of knowledge is essential and coördinated effort of many makes a complete design.

Team work can certainly begin in school. Student and teacher should form a team; the other members of the class contribute to the joint effort. Branches of the national societies will introduce students to the technique and philosophy of society organization. In the student branches a study may be made of the other national societies and the activities of E.C.P.D. Discussions may be organized about the registration movement and its effect on the engineering profession; study should be made of unionism and its threat to professional integrity. These and other topics should engage the attention of the undergraduate in order that he may have a professional attitude toward group problems as he enters the profession.

Finally a place must be found for a study of the ethics of the profession. Here should be stated the principles which govern the relation of the practitioner to his employer, the practitioner and the public, the practitioner to other practitioners, and surely the relation of the practitioner and his employees. Most of the codes of practice forget the relation of the engineer to his employees because the codes have been written to govern the practice of the consulting engineers and it has been assumed that he will know how to treat his helpers. Since a great majority of the members of the engineering profession are employees, the codes of ethics of the future must state the relation of the engineer-employer to his employees. Many of the problems now facing young engineers are an outgrowth of the neglect of engineers in positions of influence to see to it that their engineer-employees have a fair consideration when salaries are fixed.

To summarize let us say that regular courses in the engineering program lend themselves to professional interpretation. To succeed in growing a

professionally minded group, the whole faculty must work as a team in producing a professional atmosphere. Surely it goes without saying that no professional concept can have roots or grow where the teachers are not professionally minded. Begin with meetings of the faculty, determine the road that should be traveled, and then check from time to time the direction signs to make sure that progress has been made in the right direction.

Necrology

HERBERT M. DIBERT, Secretary-Treasurer and Sales Manager of the W. and L. E. Gurley Company, died suddenly April 7, 1945, at his home in Troy, New York.

Mr. Dibert was graduated from Rensselaer Polytechnic Institute in 1908 with the degree of Civil Engineer. During the years from 1908 to 1912, Mr. Dibert served as an instructor in Civil Engineering first at Rensselaer and later at the University of Pennsylvania. In 1912, Mr. Dibert entered the employ of the W. and L. E. Gurley Company and since that time had risen to the executive position which he held at the time of his death.

Mr. Dibert had maintained active membership in the Society for the Promotion of Engineering Education since first becoming a member in 1913. He had always been active in the affairs of the Civil Engineering Division and in particular, the Committee on Surveying and Mapping, having promoted and taken an active interest in the National and Regional Conferences Sponsored by the Committee. At the time of his death he was Secretary of the Civil Engineering Division and permanent Secretary of the Committee on Surveying and Mapping. Mr. Dibert was held in the highest esteem by all who knew him as a grand fellow personally, and as an able leader whose wise counseling served this Society well.

In addition to the Society for the Promotion of Engineering Education, he was a member of the American Society of Civil Engineers, American Society of Photogrammetry, member of the Committee on Field Engineering of the American Public Works Association, Chairman of the Technical Division on Surveying and Photogrammetric Instruments of the American Congress of Surveying and Mapping, Associate Member of the American Society of Mechanical Engineers, a Fellow of the Royal Geographical Society, a member of the American Road Builders Association and member of the Newcomen Society, the Engineer's Club, the Export Managers' Club, and Shanghai Tiffin Club of New York City.

Machine Design Instruction in the Post War Period*

By PAUL H. BLACK
Cornell University

When your Chairman, Professor Ryan, extended the invitation to me to speak on the subject of Machine Design in the Post War Period, he suggested that the subject be treated so as to stimulate discussion. That part of the assignment is easy to fulfill, since it is not hard to get machine designers into discussion. A more difficult part of the assignment is to predict the future role of machine design in the light of its past and its present status. The subject can well be considered in two parts: graduate instruction and undergraduate instruction.

As to graduate instruction, it is apparent from reports of committees of this Society and other societies, such as the ASME, that graduate instruction in engineering education will be expanded in the postwar period. To one who has followed the recent developments in the general field of design, it is evident that considerable emphasis must be placed on graduate instruction in the future if its high level is to be maintained. The recent developments have been in many new fields as well as in older ones. It will be necessary to consider extensively subjects such as (1) Fatigue properties of materials including effects of stress concentration and corrosion. (2) Properties of materials at elevated and subnormal temperatures. (3) Surface finish and its tremendous effect on friction and wear and their influence on design. (4) Vibration characteristics of machinery. (5) Lubrication and journal bearing design. (6) The experimental methods of stress analysis and the interpretation of data secured by their use. (7) Dimensional analysis. Each of these subjects is a field of study in itself, but the question that arises is "Can the competent machine designer afford to be ignorant of any one?"

In addition to providing instruction in these subjects for men interested in design and development work, the graduate work serves to keep the instructional staff well informed and up to date.

Now as to the undergraduate phase, it is well to consider the objectives of courses in machine design. While the objectives vary considerably in the several institutions, the following two broad objectives are common, I believe, to most courses.

First, to develop in the student the design attitude. By this is meant an open consideration of all the interrelated factors appearing in the design problem. A consideration of these factors results in a final choice of material, process, size, form and finish of parts and their specifications, and in-

*Presented at the 52nd annual meeting, S.P.E.E. (Mechanical), Cincinnati, June 22–25, 1944.

cludes considerations of strength, stiffness, lubrication, vibration characteristics, safety, production, cost, etc. Experience in the proper application of theory including an appreciation of its limitations, and a proper use of engineering judgment, all are included in acquiring the design attitude.

A second objective is that of acquainting the student with information and knowledge of structural details of elements of machines including the units of power transmission. The latter includes belts, chains, gears, brakes, couplings and clutches, shafting, bearings, etc., and also familiarity with commercial sizes, standards, codes, etc. These two objectives may not be entirely inclusive, but they are broadly, I believe, what most of us are striving for.

Now I would like to consider a third objective. Possibly some of you are already doing what I have in mind. If so, an account of your experiences would be valuable. This objective is not a result of entirely my own ideas but those of my associates in some half dozen institutions where I have been either a student or a staff member, and also results from many discussions with my friends from other institutions both educational and industrial. The objective is that of integrating courses in the entire mechanical engineering curriculum.

The various courses in a mechanical engineering curriculum are generally given in a somewhat unrelated manner and many students go through the entire curriculum without seeing their connection, or relations. As Professor Buckingham says in his book "Production Engineering," the courses are too often of the pigeon-hole variety. Could not a properly planned course in machine design serve with advantage to do this integrating job?

The type of course I refer to would substitute for the usual machine design problem, work more of the nature of a mechanical design project. Such work may involve procedure similar to that followed in design offices. Such work may involve conceivably a consideration of thermodynamics, consideration of special properties of materials and heat treatment, etc., investigation of vibration characteristics, possibly consideration of chemical effects, characteristics of electrical machinery, etc. The introduction of such an objective would make broad demands on the machine design staff. It seems to me it would yield superior graduates in mechanical engineering and would raise machine design from just another course to a higher level of attainment where it justly belongs.

Post War Education of Foreign Students

By R. C. DISQUE
Drexel Institute of Technology

The writer was asked by the president of this society to attend a conference in Philadelphia February 28–29, 1944, to consider post war education in American educational institutions of students from the war torn countries of the world. The meeting was held under the joint auspices of the Edward W. Hazen Foundation, the Association of American Colleges, and the Institute of International Education. In attendance were delegates from twenty-four national educational associations representing practically all areas of interest in higher education and research in this country, as well as representatives of the Department of State, the Department of Agriculture, the Foreign Economic Administration, the U. S. Office of Education, the Office of Coördinator of Inter-American Affairs, and the Bureau of the Budget.

From the deliberations of the conference it appeared that the United States would, after the war, face a most extraordinary opportunity—that of becoming the educational center of the whole world. The more one considers the nature and scope of this opportunity, the more one must view it as an obligation to both our country and the rest of the world. Only the most extreme isolationist could possibly view the matter in any other light.

Let us consider the facts. Outside of the United States there are no important areas in all the world in which the educational plant and facilities are not being hopelessly devastated and deteriorated by the present war, either as a direct consequence of military operations or as a result of the deliberate policies of the axis countries, especially Germany. Even though the German institutions of higher education should emerge unscathed from the war—which is unlikely—it is obvious that they will not play a significant part in providing educational opportunities for the rest of Europe. Germany will be so feared and distrusted by all of the populations of Europe that her institutions will not be attended by foreign students for many years to come. Furthermore, German teachers and experts will not be tolerated in the war torn countries. In fact leaders of the countries of Europe are now openly giving expression to this attitude.

It seems clear, too, that Great Britain will be in no position to meet any large part of the need, because her own institutions will be wholly inadequate to catch up with her own needs, to say nothing of the proposed extension of her educational opportunities beyond those of the pre-war period. This arises not so much from the destruction of the educational plant as from the decimation and dispersion of her faculties.

On the other hand, the facilities for

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higher education in the United States will no doubt emerge from the war practically intact. While a certain amount of obsolescence and depreciation of equipment will have set in and the faculties will to a certain extent have been dispersed, restoration of their normal degree of effectiveness will be comparatively rapid. Our country will offer the only hope of anything like satisfactory educational opportunities on the higher levels in the whole world.

But the war torn countries of Europe will not be alone in their demands on our educational facilities. Account must also be taken of the needs of such countries as China, India, Africa, and South America, all of which have even in normal times looked beyond their own borders for much of their higher education. In the past, many of these countries have sent their students to Germany; but again, fear and distrust of Germany will cause them to look elsewhere after the present war.

Such studies as have been made of the educational needs of the post war period indicate that three kinds of training and education will be required: (1) Short courses of two, four, or six months, in agriculture, food processing, simple medicine and hygiene, business administration, social service, and engineering. (2) Accelerated professional and scientific courses in medicine, sanitation, nutrition, education, applied science, social service, and business administration. (3) Full collegiate and university work, both graduate and undergraduate, in practically all fields. It seems clear at the moment that all this work will have to be done in institutions above the high school level.

The conference in Philadelphia concerned itself with the questions which must arise in the minds of everyone, namely: (1) How large will the program be? (2) How can this burden be added to the heavy load which American colleges will have to bear in caring for our own country's post war needs? (3) How can the program be financed? (4) What coördinating and administrative bodies will have to be set up to put it into effect?

In regard to the size of the program no definite statement can as yet be made. It is reasonable to believe, however, that the minimum number will be about five thousand a year, or a total of twenty thousand in attendance at any one time. It should be pointed out that this would not be a significant addition to our normal student population of 1,300,000. It may certainly be presumed that our educational institutions will find ways and means of meeting this obligation. If all of the educational agencies, both public and private, could be mobilized and coördinated the work would no doubt be easily done. It is to be remembered that our educational institutions have not been notably efficient in their utilization of time and space available. Our schools and colleges have for the most part operated only part of each day, part of each month, and part of each year. By raising their time and space utilization factors, they could do enormously more than they have ever done in the past.

Bearing on the same question are the extensive educational facilities of the industries themselves which have so far hardly been touched. It is altogether likely that foreign students, particularly those in engineering, will wish to become familiar with American industrial practice as rapidly as possible. This might well call for the adoption of the coöperative principle

on a very large scale. It may be that industrial periods will be spent in the homelands of the students themselves, thus accelerating the restoration of the industries of those lands and easing the burden on the educational institutions. To these may be added the many educational projects which the departments and bureaus of the federal government regularly conduct. It seems reasonable to believe, therefore, that means can be found for bearing the additional burden on the American institutions if the will to do so is strong enough.

The third question relates to financial support of the program. This problem seems, at first sight, to be a very formidable one. But a study of conditions in this country reveals that it is not by any means an insoluble one. There is first of all the possibility of support from our own federal government, which is very deeply interested in the international aspects of the projects. Evidence of this interest is found in the attendance at the Philadelphia conference of representatives of six federal agencies. There are also numerous philanthropic foundations, many private funds, civic groups, labor organizations, national groups, foreign governments, and other agencies too numerous to mention, all of which add up to a very large reservoir of financial resources.

In regard to the last question, it goes without saying that many and various administrative problems will have to be solved in order to implement the program. Many of these, such as immigration restrictions, exemption from military service, and tax laws, will necessarily be handled by the federal government departments and by government personnel in various parts of the world. So far as these aspects of the administrative problem are concerned, we can be sure that the Department of State, as well as all the other federal departments, will coöperate with the utmost enthusiasm. In fact, these departments have been studying the matter for a long time and may be expected to issue a formal statement of policy in the near future. The colleges and universities will likewise have to face many difficult administrative problems in order that large numbers of foreign students may be absorbed in their student population with maximum of effectiveness. These problems will pertain to the selection and guidance of the students, their placement in the various levels of the curricula and in industry, to their social and educational adjustment, and to many others. In order to meet their obligations, the colleges and universities in America should certainly include these matters in their post war plans.

Two practical steps were taken by the Philadelphia conference. One was the adoption, after thorough discussion, of the report of the Committee on Findings. This report is a comprehensive statement of the consensus of opinion of the entire conference, and it is therefore quoted here verbatim:

> The representatives of American Educational Associations here assembled recognize the importance and urgency of coöperation with Government in providing facilities for the education of students from the war-torn countries. We recognize this as a great opportunity for the United States to coöperate with the peoples of these lands in establishing a stable postwar world.
>
> It is evident that the war-torn countries will be desparately in need of assistance in educational and cultural reconstruction after the war. Our people very properly will wish the Government of the United States to coöperate in this program. In doing so, the first step may

be to negotiate bilateral agreements for the reception and exchange of students and teachers; and to do this in collaboration with the institutions and agencies representing both publicly supported and privately supported education in the United States.

We believe that education of students from other countries is primarily the function of our existing educational institutions. We anticipate, however, that the magnitude of the task will require supplemental support from our Government, in addition to that which will be supplied by other Governments, the institutions themselves and by other agencies.

In coöperation with the U. S. Office of Education, other Government departments and with educational institutions and other agencies, the Department of State should formulate the general policies governing this program, based upon the determined needs. It should also negotiate agreements with foreign governments and obtain, in collaboration with other agencies, the necessary data on which the program is to be founded. It should survey existing and proposed legislation and immigration procedures, with the view to facilitating the entrance and residence of students from other countries by removing unnecessary restrictions upon such students and also with the view of extending privileges enjoyed by such students to trainees from other countries who come for training in industrial, business or governmental agencies.

The educational institutions and agencies should provide information as to their resources and facilities. They should undertake to adapt their regular curricula to the students coming to the United States or organize other programs to meet the particular needs. Where possible, they should provide some assistance to the students.

The sponsors of this conference are authorized to organize a small provisional continuing committee, consisting of representatives of educational associations of the country. This continuation committee shall coöperate with officials appointed by the government in the formulation of such a program. It should assist in formulating policies regarding an appropriate program. It should plan procedures for enlisting the resources of educational institutions and agencies making use of available experience and facilities. It should enlist public interest and support.

The second step was the appointment of a Continuation Committee as recommended by the Committee on Findings. The members of the Continuation Committee are as follows:

Esther C. Brunauer, American Association of University Women

Lindley H. Dennis, American Vocational Association

Luther P. Eisenhart, National Research Council

Willard E. Givens, National Education Association

Walter Hullihen, National Association of State Universities

George Johnson, National Catholic Welfare Association

Roscoe L. West, American Association of Teachers Colleges

Stephen Duggan, Institute of International Education

Guy E. Snavely, Association of American Colleges

Paul J. Braisted, The Edward W. Hazen Foundation

In view of the fact that engineering and applied science will constitute a very large part of the project hereinafter described, this Society should prepare itself to take its share of the work of planning the program. It is recommended, therefore, that the next administration of the society include this project in its list of obligations for the coming year. What form this coöperation will take must depend on the work of the Continuation Committee which should formulate and announce its plans in the near future.

The Know-How of Industry*

By WALLACE CLARK

Consulting Management Engineer

Every industrial enterprise has a plant with buildings, machinery and equipment, and it also has materials and workers, but all these are useless unless it has the know-how—both technical and management—for running the business. Technical know-how, or knowledge of production, in manufacturing includes research, development, design and all other work done in an engineering department; the mechanical, electrical and chemical production in the plant itself and the inspection or testing of the product.

Management

The know-how which is called management includes the whole body of knowledge concerned with getting work done. The technical branches of engineering received their principal development during the 19th Century, but it was only at the turn of this century that the pioneers, Taylor, Gantt and the Gilbreths, conceived the idea that management also is subject to laws and principles and that technics could be worked out which would be comparable in accuracy and value with those of mechanical or civil engineering. The vision of these pioneers has been realized and we now have a body of management technics based on scientific principles whose value is almost universally recognized.

As they were first worked out, methods of management were rigid and rather complicated. Gantt took the first steps to humanize them, insisting that they must be sufficiently clear and simple so that they could be understood by the people who used them. Since that time continuous progress has been made in simplifying the methods, adapting them to various needs and training people in their use.

These are the principal technics which make up the "know-how" for managing a manufacturing business:

Production planning and control, consisting of methods to secure a rapid and even flow of work through a plant. This includes advance-planning, load of work ahead, daily schedules and records of performance.

Plant layout; that is, locating machines and equipment so as to secure the best conditions for workers; the desired quality of production; the shortest time to manufacture and economy of transportation.

Improvement of processes; that is, by means of motion and time studies, finding the best way of doing work from the point of view of quality, quantity and fatigue.

* Presented at the 52nd annual meeting, S.P.E.E. (Industrial), Cincinnati, June 22–25, 1944.

Purchasing materials at reasonable prices to meet requirements as to quality and delivery.

Storeskeeping, which makes sure that materials will be on hand when needed.

Personnel management, which includes the selection and training of workers and all relations with unions and their representatives.

Wage payments, including rate setting and incentives.

Costkeeping, which aims at reducing future costs.

Budgeting of overhead expenses.

Planning of sales, which begins with market analysis and includes methods of selling and of comparing results with quotas.

Financial planning, to provide the money necessary to operate the business and to secure a satisfactory turnover.

Executive control of the business as a whole, which maintains a balance of development, production, sales and finances.

In some enterprises these methods are highly developed and well understood by the supervisory personnel. In other plants their value is not yet realized.

Methods of Installation

During recent years consultants and company executives responsible for organization methods, have developed special technics of installation. These comprise: the analysis of existing methods and the determination of needed changes, and technics of introducing new methods and getting them accepted and used.

The technics which have been outlined are the tools of the management engineering profession, not only of consultants but of engineers who practice as executives or staff of a manufacturing company. Skill in the use of these tools cannot be acquired quickly or easily. Years of study and practice are essential.

Our own company might be considered more or less typical of consulting firms. I had the good fortune to learn the principles and basic technics from Gantt and the Gilbreths. That was followed by twenty-four years of intensive practice as an independent consultant. The methods we use were hammered out on the floors of hundreds of shops in this country. During fourteen years in Europe we tested these American technics in the industries of twelve countries. Since 1939 we have applied them continuously to war production, both in Government and in private industry.

Other consultants have methods which are similar in some ways and different in others, but all those of accepted standing in their profession have developed, with hard study and much experience, a body of technics which can be adapted to practically any kind of industry.

With the development of this know-how in industry there has been parallel progress in teaching the principles and technics of management. What industry needs now is more management engineers who have been trained in our universities. Industry needs also to develop more effective ways of giving these engineers experience in practical shop work.

If possible, the student or young executive should be trained in all of the management methods. Later he may become a specialist, but he will be a better specialist if his education and training are well rounded.

Obviously, the relative importance

of the standard management technics varies in different periods. During the depression of the '30s, when there were more machines and workers than were needed, planning became easier and less attention was paid to it. Executives concentrated on reducing costs of material, labor and overhead, releasing money tied up in inventories of equipment and materials and on sales and financial planning.

This situation changed quickly during the months before our entry into World War II. Planning came into its own. Production planning took its place at the head of the line and timing became of first importance. War material got into production at a speed unheard of in peace times. Changes in design were made during production without seriously interfering with output. Special attention was given to the expediting of purchases and subcontracts, the improvement of processes by motion and time study and the training of personnel.

In these war years little attention has been paid to costkeeping or to sales. Finances have been easier to handle because profit margins have been generous, the Government has paid invoices fairly promptly and has made most of the capital investments. Incentives were almost forgotten until this year.

As we enter the post-war period there will be another shift in emphasis. Production planning will continue to be most important because of the quick change from war to peace production, which will be required in order to avoid unemployment. Shortages of materials and uncertainty of demand will also require flexible planning. Plant layouts will have to be revised because of changes in products. Costkeeping and incentives will resume their importance because of keen competition. For the same reason, sales planning will be a critical need and high taxes and changing markets will require expert planning of finances. The technics of executive planning and control will be in great demand.

The "know-how" of management includes not only the standard technics and the methods of their installation. The third requisite, and one which is of equal importance, is the attitude of the management engineer toward the people with whom he works. He should understand that the management of industry can be improved only as the people in it are developed. He should like people and believe that they can do things which are beyond their past experience or capabilities. He must be an optimist in regard to human nature.

He should understand that men do not work for money only and that much of their satisfaction comes from doing a good day's work and from the commendation and respect of their fellow-workers, employers or the community. The desire to be of service to others is often a stronger motive for action than self-protection. The management engineer who understands people will act on the basic assumption that every man wants to make good on his job and that the best way to get a change accepted is to show an individual how it will help him to make good.

In this important part of management know-how, the young engineer needs expert guidance to develop principles on which to base his working relations with others. He must learn that good will is no substitute for technics; that it is the proper balance of the two which makes a science of management.

The use of management technics has a strong influence on human relationships. Planning brings an agreement as to what is to be done, who is responsible for doing it and the dates on which each one is to begin and complete his part. (Of course I do not refer to mere paper planning, of which so much is being done these days.) As it is carried out, progress is compared with the plan both as to results and time. This removes most of the petty irritations and misunderstandings which follow lack of agreement. The executive is reasonably sure that each of his staff understands what is expected of him and the latter in turn knows that his point of view has been taken into consideration in preparing the plan.

Expense budgets have the same influence on human relationships. They represent a meeting of minds as to what should be spent to attain a certain result, and give to a subordinate the limits within which he is free to act on his own initiative.

The proper use of these technics ensures relations that are frank, open and aboveboard. That is what we like to call the American way of doing business.

Field for Management Engineering

The field in which the trained management engineer can work is very broad. Here in our own country much remains to be done to bring all industry up to the standards which have been set in a few companies. The general acceptance and reasonably efficient use of the technics already known would more than double production. This would increase the purchasing power of the workers and broaden our domestic markets. It would also dig deeper into our inventive resources.

These technics need to be introduced into our new industries, such as electronics and plastics, as well as more intensively into research and development, and distribution.

The Foreign Field

A vast field for management engineering is opening up in foreign countries, which look with wonder and admiration at the high living standards of the American people and believe that our prosperity is the result of the industrial advances we have made during the last fifty years. Those countries want producing equipment, technical knowledge and skill in management technics. They are looking for the complete know-how of modern industry.

The so-called "occupied countries" in Europe which have been industrialized for a long time but have been cut off from progress during this war, are now looking eagerly for the best and most up-to-date technics. They want to resume leadership in their own special fields.

The countries which have not been industrialized, or have only begun, want all the fundamentals. In this latter group are Russia, China, India, Pan-American Republics and Africa. They will not look to Germany for this knowledge. Great Britain will attempt to supply it for the British Empire but will not have the resources or personnel to go far beyond that field. The non-industrialized countries prefer American mass-production technics to British "cut and fit" methods, because they want large quantities of low-priced goods for the "common man."

The United States of America will

undoubtedly take first place in industrializing other countries, because we will have:

Machines and equipment of the latest design and the capacity to turn them out in large quantities;

An increased number of technicians due to our industrial expansion during this war, and

Credits which are long enough to enable customers to pay for equipment and technicians out of the profits from production.

Plans are being prepared in several foreign countries to bring together privately-owned and Government-financed plants and to operate them as a group. This will require management engineers of more experience and vision than are available in those countries. Markets, both domestic and export, must be studied in order to determine quantities and varieties that the plants should produce. Suitable equipment must be specified and purchased. Operators will need to be trained on the new equipment so that they can use it to its full capacity. Methods of management for individual plants and for whole industries must be introduced and executives trained in their use.

Some of these countries need the rudiments of management, while others want up-to-date methods for operating groups of industries at high efficiency.

Opportunity for Service

There are few fields for the young engineer, either in this country or abroad, which offer such opportunities for service to others as does the management profession. The elimination of waste, raising quality standards, increasing production, reducing costs—all contribute toward providing a fuller life for people. Sound technics for getting work done release the creative energies and develop the latent capabilities of those who use them.

Thus the engineer takes his part in industrial and human progress.

Disposal of Surplus Manufacturing Equipment from the Machine Tool Builder's Viewpoint*

By WALTER W. TANGEMAN

Vice President, The Cincinnati Milling Machine Co.

The successful prosecution of war requires the same three essentials that are required for the successful prosecution of any business—men, management and machines. For the production of the machines of war, machine tools have always been an essential element. As armies have become mechanized, the demand for machine tools to build the guns and tanks and trucks mounts. In 1937, the biggest year in dollar shipments which the machine tool industry had had, something in the neighborhood of $225,000,000 worth of product was produced. The year 1938 was one of mild recession. In 1939 machine tool orders from Europe began to come in as a direct result of the war. They continued in 1940 and late that year our own defense program got under way and our government began to place orders for machine tools.

Astronomical requirements began to take shape and orders accelerated during 1941 to reach a peak in early 1942. Shipments in 1942 were actually between $1,300,000,000 and $1,400,000,000 as compared with the pre-war peak of $225,000,000—or almost seven times the pre-war maximum amount. The total value of the machines produced for 1939 through 1943 is approximately $3,900,000,000 and it is estimated that an additional $500,000,000 will be produced in 1944.

I believe that in 1939 we are supposed to have had in production in the United States some 900,000 machine tools of all ages. We have added since then another 900,000 modern, highly productive machines. These figures, startling as they are, do not prove that we have 900,000 surplus machine tools today. They do indicate, however, that there is in this country a supply of tools of relatively modern design to overhaul completely our industry. Part of these tools already belong to industry because they were purchased with their own funds. A still larger part belongs to the government. It is estimated that some $2,500,000,000 worth of machine tools are today in use in government owned plants and it is these tools which present the surplus disposal problem.

It is expected that in the post-war era our country will experience an expansion of manufacturing in all fields with some few obvious exceptions. It is desirable that this production be carried on with the most modern tools that can be made available so that it would seem the part of wisdom to set up a system of disposal which would permit industry to pur-

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chase tools from government surplus stocks to use in the era to follow the war.

There are other requirements, however, which must be met even before industry can expect to receive consideration. At the very top of the list would seem to be the requirements of our armed services for every bit of machinery that they decide is necessary, first, to put their establishments in first class shape, and second, to build up whatever reserve of machine tools may be deemed necessary to guarantee our military production for at least ten or fifteen years ahead. Such a reserve supply or reservoir would consist of selected production lines and even entire production plants for necessary military articles and in addition vast storehouses of standard machines of all types which can be drawn on in case of any emergency.

It is difficult to say just how big this reserve stock of machine tools should be and until surveys have been completed of all government establishments, we will not know just how many machines will be required to revamp completely these establishments. However, we do know that large numbers of machines will be set aside for this purpose. It is extremely important that this selection be made promptly because these machines must be moved out of contractors' plants in the shortest possible time after war contracts are completed so that plants can be reconverted to peace time use. The government must act rapidly on this matter if the whole conversion problem is to go forward promptly.

After the military requirements have been completely filled, then it is clearly the intention of the government to offer the additional surplus equipment to industry. Many plans have been proposed. Some of them sound purely political in character. At least eight or ten bills purporting to settle the disposition of this equipment are in Congress now. Some of them give prior rights to returning veterans, some to small business, and many overlook entirely the main problem which would seem to be to get these machines out of the plants where the floor space is needed for post-war work and into shops where they can begin to produce and add to our economy. Many also overlook the fact that much of this equipment has been installed under forms of contract which give to the user first right to purchase.

The government will attempt to sell as much of this surplus as possible at the best prices it can secure. It seems desirable that if possible a formula be evolved for pricing the various machines. Considerable work has been done along these lines and the pricing policies are now taking shape. I am afraid that at the moment the thinking in Washington is to sell all the machines that can possibly be sold, and then when they can no longer obtain orders for what is left, offer the educational institutions these particular machines. In fact, one of the bills now before a congressional committee investigating this whole matter of surplus materials, contains the following paragraphs:

"Whenever the government agency authorized to dispose of any property finds that it has no commercial value or that the cost of its handling and sale would exceed the estimated proceeds, the agency may donate such property to any agency or institution supported by the Federal Government of any state or local government or to any non-profit educational or chari-

table organization, or if that is not feasible, shall destroy or otherwise dispose of such property.

"To afford public, governmental, charitable and eleemosynary institutions and coöperative organizations an opportunity to fulfill their legitimate needs for surplus property."

If you read these paragraphs literally, you come to the conclusion that only machine tools that have no commercial value can be donated to educational institutions. Obviously, this is not what you want or should have. Inasmuch as the actual dollar value of the machine tools required to re-equip properly the mechanical laboratories and maintenance departments of our universities is extremely small compared to the total value of machine tools in the government's hands, it would seem as if these relatively small numbers of machine tools could be taken out of surplus even before the machines were offered for sale to the public.

It is time for our educational institutions, particularly our technical schools and colleges, to place more and more emphasis in their laboratory work and in their teaching upon the production of goods because after all it is America's ability to produce as well as to invent that has made her a great nation and underlying all production of goods are machine tools. So it should not be too difficult to convince your legislators that colleges and universities are entitled to and should have high-grade machine tools in such quantities as they can properly use and I see no reason why they should not be turned over without cost or at very little cost. There will be great emphasis on the education of our returning veterans and there is no question but that in the years to come more and more students will enter our colleges and universities. Machine shop practice must become a more important course of study and it should be taught on modern tools.

However, this desirable result will not happen unless you gentlemen take an active interest in the plan. Your case has to be well presented not only to the special committees that deal with this subject, but to every congressman. You must present, as it were, a budget of your requirements. This can be made up only by summarizing the carefully prepared lists of machine tool requirements of each institution. In preparing the lists, by all means be specific. Indicate the electric current you have available and, if possible, the attachments you would like to use. Include also other items of machine shop equipment because many of these will be in surplus as well. If possible, I should think it would be well to indicate by contact with industrial concerns who have this equipment in your vicinity, where the machines can be secured and then above all, make the necessary arrangements to remove them promptly if they are finally turned over to you.

The machine tool industry is all for seeing our educational institutions properly equipped with machine tools and this seems to be your golden opportunity but it must be carefully followed up through proper channels and your case everlastingly kept before the proper committees. I am quite sure the National Machine Tool Builders' Association would be glad to help any institution prepare a list of the machines it should have for either laboratory purposes or maintenance and there is a machine tool builder certainly in your neighborhood who can render you valuable assistance.

Teaching Methods in Engineering Analysis*

By B. R. TEARE, JR.
Carnegie Institute of Technology

Engineering Analysis is a course to develop facility in the use of orderly method—the engineering method—in solving engineering problems. It is one in which the primary emphasis is placed on method rather than on subject matter, and in which the subject matter with which the method deals cuts across the boundaries of customary academic fields. It is the purpose of this discussion to describe the features of such a course from the point of view of instructional methods. Indeed, the course as a whole is a method of accomplishing an educational objective that in general has not been achieved in other, traditional courses.

In the past decade there has been an increasing interest in engineering analysis as is indicated by the growing number of schools that have courses similar to the ones to be described. This interest is reflected in the textbooks available, of which several have been published covering the mathematics used in engineering analysis, and recently a book † appeared which gives a good integration of both mathematical and physical principles that are employed, and which is suitable for use at the undergraduate level.

The need for such a course grows out of the realization that for the most part four-year graduates are well trained in certain specific applications in their field but are unable to deal successfully with problems that they have not previously encountered, problems that may be simply solved by the application of such fundamental principles as Newton's laws of motion or the law of conservation of energy. The student is familiar with fundamental laws in the somewhat superficial sense that he can state them adequately and can readily comprehend their use by someone else in solving a problem, but ordinarily he does not have such a thorough grasp of them that he can assume the initiative and apply them successfully himself in new situations. In many of the subordinate positions that the engineering graduate may fill a speaking knowledge of the laws will suffice, but in the more technically exacting positions, a speaking acquaintance with fundamental principles is not sufficient and a real working knowledge is required. Dealing with new situations is so extremely characteristic of the high level technical positions in engineering that it may almost be said to be definitive of them. Reputations are not made in the profession merely by being familiar with what has gone before, nor by facility in the use of handbooks.

Lack of the understanding requisite

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†"Mathematical and Physical Principles of Engineering Analysis," by W. C. Johnson, McGraw-Hill, New York, 1944.

for competency has been discussed by President Doherty in the proceedings of this Society * and elsewhere, and others familiar with the industrial picture have concurred in his opinion. It was to supply adequately trained men, men that perhaps should have been trained in the colleges, that Doctors Doherty and Stevenson in 1923 organized in industry an Advanced Course † for engineering graduates which has set a pattern and done much to stimulate college courses in engineering analysis. Many of the educational concepts to be discussed here had their origin in the stimulating experience of being a student in that course.

The ends toward which the course in engineering analysis is directed have been given in the 1940 Report of the S.P.E.E. Aims and Scope Committee as one of the objectives of the scientific-technological stem:

> Thorough understanding of the engineering method and elementary competence in its application. This requires:
>
> (*a*) comprehension of the interacting elements in situations which are to be analyzed;
>
> (*b*) ability to think straight in the application of fundamental principles to new problems;
>
> (*c*) reasonable skill in making approximations, and in choosing the type of approach in the light of the accuracy required and the time available for solution—in sum, a foundation for engineering judgment;
>
> (*d*) resourcefulness and originality in devising means to an end;
>
> (*e*) understanding of the element of cost in engineering and the ability to deal with this factor just as completely as with technological factors.

And this objective is again emphasized in the recent report of the Committee on Engineering Education after the War.

It is possible and highly desirable that the chosen objective be accomplished not only in a single course but in all of the courses of the scientific-technological stem. Indeed there is probably no course in which it is completely overlooked. However, experience seems to indicate that the requisite elementary competence in the engineering method has not been developed as a by-product of lectures and class exercises whose purpose is the imparting and explaining of subject matter. Something further is required, either an overhauling of many of the classes to throw more emphasis on engineering method or the deliberate use of a course designed to accomplish this end. The latter procedure is exemplified by the course in engineering analysis.

Engineering Analysis seeks to develop an elementary competence in the engineering method by the active participation of the student in analyzing situations that are new to him. Suitable exercises for this purpose are those which provide an appropriate situation to be analyzed, together with a guiding discipline, but in which the student must assume the initiative. Thus the courses in engineering analysis are problem courses, but not the ordinary kind of problem courses; and the educational advance occurs to a large extent in the work the student

* "Readjustment of Policy and Program in Engineering Education," Robert E. Doherty. JOURNAL OF ENGINEERING EDUCATION, Vol. 25, September 1934, pp. 26–48.

† "An Advanced Course in Engineering," A. R. Stevenson, Jr., and Alan Howard. *Electrical Engineering*, Vol. 54, March 1935, pp. 265–268.

does outside of the classroom in solving the assigned problems.

The choice of problems with respect to what is required for their solution is of the utmost importance. A suitable problem is one that presents an engineering situation that is relatively new to the student and one for which the solution is to be obtained not by substitution in handbook formulas, but by the *application of fundamental principles*. The solution may involve deduction from some established generalizations of science, or the opposite process of establishing a rational reference from observed or given data, or the creative process of devising. Since the problem is built around an engineering situation it must be studied to see what the important elements are, a method of solution must be selected and applied, and usually simplifying assumptions must be made. Finally when a solution has been obtained it must be checked as carefully as possible and engineering conclusions must be drawn from the mathematical results. Some of the problems should involve cost as an important factor.

The procedure of solving problems may in many cases be summarized as first, the expression of a given situation in terms of a mathematical equation, second, the solution of the equation making use of other subsidiary relationships, and third, the checking of the solution and its interpretation as a useful engineering result. That is, the treatment of the problem involves translation of an engineering situation into mathematical language, mathematical manipulation, and translation back into engineering terms again. For the most part students are able to handle the middle step, that of mathematical manipulation, but they lack facility in the first and third steps. Thus the engineering analysis course should put considerable emphasis on these less common steps and afford practice in doing them.

Problems should also be selected with motivation in view. Properly selected problems afford an unusual opportunity of stimulating student interest. In general it has been found that currently appearing technical papers and the teacher's own research are rich sources of problems and by the inclusion of some descriptive technical background the student can be made to feel that he is practicing the engineering profession (as he actually is) and not merely executing scientific calisthenics in preparation for it. Further interest occasionally may be added by framing the problems in such a way that the answer is unexpected or the hastily guessed answer is wrong, and by providing a few pitfalls for the unwary. However, these devices must be used sparingly so as not to lead to the formation of wrong impressions or to discourage the student. They should be directed to the establishment of confidence in the use of fundamental principles, and fundamental principles alone, in the handling of new problems.

That the stimulation of student interest is an important function can scarcely be questioned. The teacher cannot but look with envy at the unbelievably high level of interest, in terms of college standards, that is found in the advanced course already mentioned. This may be traceable in part to the quality-producing process of selection and to the spirit of competition between those so selected, and in part to the spirit of competition between those so selected, and in part to the stimulating problems that are used. (Also, it is not inconceivable that putting the student on the payroll

of the department giving the course, plus the fact that his showing in it affects his future promotion, has something to do with his interest.) On the other hand student interest in college work rarely is great enough to constitute a major driving force, and often it is not comparable to the interest in extra-curricular activities. A good method of motivation is badly needed. One of the best stimulating forces is the experiencing, by the student, of an increased intellectual power which he recognizes, a capacity to understand and to get results that he did not previously have. And this stimulus can readily be developed in the course in engineering analysis.

As important as the type of problem is its degree of difficulty. Good engineering problems may be found at all levels, but a problem that is too easy or too difficult is of little educational value. A problem should be hard enough to tax the student's intellectual powers and give him a feeling of achievement when he has obtained a solution, yet not so difficult that he is discouraged. A particular problem may be suitable at one level of progress, too difficult at an earlier time, or too easy if assigned later. Thus, it is important not only to select good problems, but also to assign them at the right time.

Since the course in engineering analysis deals primarily with method, it can be designed for almost any level, either elementary or advanced, as well as for any branch of engineering. It has been given to juniors, seniors, and first year graduate students, with appropriate differences in the degree of difficulty of the problems involved. Also, it is likely that such a course could be used to advantage even before the junior year to increase the student's command of the work covered. If a student has taken engineering analysis in both junior and senior years and has mastered the methods covered there it is probably uneconomical of time for him to take a third year at the graduate level.

The specific subject matter covered may be chosen from a wide range of possible topics. The emphasis in the course is on the use of previously studied principles and techniques in the handling of new situations, thus the introduction of new principles should be definitely subsidiary to the use of the old ones. The topics involved in the problem work are those from the mathematics, physics, and engineering courses previously studied with a few new ones sparingly introduced to round out the background. The topics include principles, concepts, and points of view from mechanics, fluid mechanics, thermodynamics, heat transfer, electric and magnetic fields, electric circuits, and electromechanical systems, as they may occur in problems that arise in the student's major engineering field. And this occurrence determines in part the relative time devoted to problems in each particular field.

It has been found desirable to begin with problems in the field of mechanics because mechanics situations and concepts are least abstract and hence easiest to visualize, and the mechanics concepts of force and work are basic to the concepts in other fields; for example in the definitions of charge and potential. Also, and especially important when the course is given at the junior level, most of the student's background has been in mechanics.

Mathematics plays an important role in the course, and much of the work even at the junior level involves

differential equations of a simple type, the second order linear differential equation with constant coefficients. However, the assigned work is not restricted to problems that require differential equations; some are solved by graphical means and the student is required to choose the appropriate method. Also the use of mathematics is accompanied by thinking in terms of physical pictures. Students are expected to use free hand sketches as much as possible, not only to portray the situation being considered and for the careful location of coördinates, but also to show results and for a thorough comprehension of the mathematical forms involved. For example a curve may have its highest point at a place where the slope is not zero if the curve is discontinuous there, and thus in looking for maximum points an important value is likely to be overlooked if formal procedures are followed without curve sketching. Pitfalls such as this usually are not discussed before they occur in assigned work; rather the student is put on his own to avoid them and they are later discussed in class.

To instill in the students the proper respect for accuracy of results and the ability to obtain them is an important and often a rather difficult goal for the teacher. Accuracy is achieved by relentless checking by all the means the problem solver can devise. Dimensional checks should be used whenever possible, and also checking by letting the variables assume significant values. The common emphasis on teaching the student to calculate by the shortest method, desirable as it is, may be responsible for undesirable by-products: an unwillingness to question the validity of methods, a lack of enthusiasm for using fundamental principles, and a tendency to consider the solution correct without painstaking checking. These undesirable attitudes should be corrected by the instructor whenever they are apparent. In engineering practice, when the graduate does not have an instructor to lean on and colleagues all working the same problem to check with, he has to get an accurate answer. And in most cases there will be sufficient time for checking, even for working the problem by several methods should this be possible. Speed should not be considered a substitute for accuracy.

The engineering analysis course may fulfill another function in addition to developing facility in applying principles to the solution of new problems; it gives an opportunity to review the principles themselves and to remedy deficiencies in each student's background. Planned repetition serves a useful end in education and strengthens interrelations between principles. In presenting a new subject the instructor can relate it to the material that has been previously studied but not to the material that is to come. The extensive review possible in engineering analysis permits a two-way connection, backward and forward.

The principles are not really understood until the student places them properly in the structure of knowledge; until he has classified them as generic principles, basic assumptions, empiricisms, derived principles, or specifications and standards, to use the descriptive terms of President Rogers.* Many problems involve laws in each category and it is impor-

* "Engineering Courses: Their Objectives, Organization, and Direction," by Harry S. Rogers. *Mechanical Engineering*, Vol. 64, March 1942, pp. 208–210.

tant to know with what type of law one is working. A new situation may be such that customary assumptions are not adequate or perhaps an empiricism may be of doubtful validity. But one may have confidence in the generic principles. The cynic's comment that "figures don't lie but liars can figure" has its element of truth in the fact that in some cases at least the methods of figuring are not properly applicable.

A common type of error made by the graduate with ordinary training is the attempted use of a derived principle in a situation in which it does not hold. As a very elementary example, in calculating distance in terms of time for an accelerating body he may try to use the equation $s = \frac{1}{2}\ at^2$ even when the acceleration is not constant. An appreciation of the origin of this law can minimize the danger of such errors. And in addition the student should develop the habit always of handling new situations by means of generic principles.

The classroom activities are conducted in a manner to promote the maximum of student participation. It is desirable to present a methodical approach to new problems for the purpose of helping the students organize their thinking processes, to review scientific principles that are being used, to work problems as examples, and to discuss student solutions. Originality should be encouraged, and original solutions by students should be brought to the attention of the class. It is important that the instructor grade and return problems promptly. In general the use of lectures is to be avoided. Blackboard work provides an opportunity for each student to work individually with some help and criticism from the instructor.

In summary, it may be said that the course in engineering analysis is directed toward developing an elementary competence in applying the engineering method in new situations. It is built around problems which must be chosen with due regard for the type of thinking required in their solution, for the interest they stimulate, for the difficulty they present; and they must be assigned at the right times. The course provides an opportunity for the instructor to ascertain and remedy deficiencies in the students' understanding of the basic science they will employ. Classes are conducted and work is assigned to require the maximum initiative from the student.

Teaching Methods in Engineering Applications*

(Teamwork Among Students)

By F. T. MAVIS† and F. W. EDWARDS‡

The Pennsylvania State College

Scope and Objective.—The pattern of engineering education was broadly defined in 1940 by the S.P.E.E. Committee on Aims and Scope of Engineering Curricula[1] and has been reaffirmed in 1944 by the S.P.E.E. Committee on Engineering Education After the War.[2] Coherent sequences of subject matters in both the scientific-technological stem and the humanistic-social stem are essential, and so too is an introduction to the *art of engineering* and the development in the student of an elementary competence in the engineering method. "Unless instruction includes the elements of the arts of practice it will be in science rather than in engineering."[3]

The process of *learning* the subject matters of engineering is initially and essentially one of science—the acquiring of "knowledge of facts, laws, and proximate causes gained and verified by exact observation and correct thinking" and the collation of "an exact and systematic statement or classification of knowledge concerning some subject or group of subjects" which bear on the life and work of the engineer. The process of *applying* the tools of engineering thought—the laws, assumptions, data, and codes so as to accomplish a desired result safely and economically—is an art. An introduction to the art of engineering and the development of elementary resourcefulness, skill, experience, and judgment can and should begin in college. "Throughout the whole fabric of engineering education, therefore, there must be interwoven with scientific principles, the development of rudimentary skills of execution, understanding of the limitations in the application of principles to practical situations, the beginnings of powers of decision and of judgment, the encouragement of creative talent, ability to deal with the factor of values and costs, and the acquirement of that appreciative sense which is satisfied only by skillful execution or precise verbal expression."[3]

The student in civil engineering has a broad field of subject matters in which to learn elementary engineering applications at the undergraduate level. Depending on his major interests—and sometimes dictated by available

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* Presented at the 52nd annual meeting, S.P.E.E. (Instructional Methods), Cincinnati, June 22–25, 1944.

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[1] JOURNAL OF ENGINEERING EDUCATION, Vol. 30, pp. 555–566, March 1940.

[2] JOURNAL OF ENGINEERING EDUCATION, Vol. 34, pp. 589–614, May 1944.

[3] *Loc. cit.*, p. 599.

options or project courses—he may apply his tools of engineering thought to a simplified problem in the field of hydraulic, or sanitary, or structural, or transportation engineering, or engineering construction. Regardless of the "specialty" which the student may *think* he is choosing, the instructor in engineering applications can lay out for him a sound program of training which develops concepts, judgment, habit, and skills that are equally applicable in other subdivisions of civil engineering. Toward this end there must be common objectives of the applied courses and we consider them to be something as follows:

1. To stimulate students to observe things of significance in full scale and in balanced proportions.
2. To focus rational and fundamentals in many fields on one assigned problem.
3. To introduce students to engineering teamwork and to assist them in planning and carrying out an assignment by squads.
4. To develop judgment and a sense of "what's-worth-doing" by observation, analysis, specification, expedience, or intuition.
5. To habituate the completion of a job in good engineering form—systematically, neatly, consistently, adequately—and to leave a record of it which cannot be misunderstood.

How can these objectives be realized? The possibilities are numberless. Half-day field trips carefully planned around a specific assignment can do much to stimulate students to observe things of significance in full scale and in balanced proportions. Purposeful reports of those field trips help to make the impression lasting. Teamwork in gathering information, in summarizing and analyzing data, and in reporting is spontaneous once the larger job is planned functionally and each unit assignment is accepted as a squad responsibility by its leader. Spontaneous teamwork can be generated in the field or in the drafting room by *subdividing* a job into smaller *different* units and *scheduling* each unit to be done by an appropriate squad or subsection. The instructor has limitless opportunity to heighten students' interests by weaving their on-the-spot suggestions into the execution of a general plan.

The common lecture-recitation method of instruction may be effective in *teaching* the student the sciences which are essential to engineering analysis and leading him further and further into the interesting branches of engineering. While proceeding in that direction it may be easier, and sometimes necessary, to "keep the class together." We believe that the lecture-recitation method is not the most effective method, however, of stimulating each student *to learn* to formulate a problem and to observe its elements, to be resourceful and original in devising means to an end, to think straight in applying fundamentals to new problems, to develop his own judgment (rather than his memory), and to acquire a sense of fitness in all he does. We believe a better way to develop originality and leadership and initiative—in short, a better way to stimulate a student to learn the elements of the *art of engineering*—is to give him responsibility as a member of a small group in which even the mouse will gnaw the rope that limits the squad's action.

Teamwork on Field Trips.—Early in the course in structural design it has

been our practice to take the class in the field to observe and gather information about a plate girder and a short truss bridge. Usually one half-day period is devoted to each type of structure. The job is planned in advance and the class is divided into squads of two or three men, each with a definite assignment. The assignment would be something as follows for the plate girder bridge:

Squad 1. Make a location sketch of the structure and obtain waterway information with the aid of compass, sketch board, and hand level.

Squad 2. Obtain over-all measurements of the structure: span, width, depth, angle of skew, roadway or rail grade with respect to the structure, and location of intermediate stiffeners.

Squad 3. Sketch and dimension piers and abutments.

Squad 4 and 5. Sketch and record detailed information about web, flanges, and stiffeners, and rivets for assigned sections of girder.

Squad 6. Sketch and dimension lateral system and cross-frames.

Squad 7 (dividing time with Squad 6). Warn against approaching trains.

Each squad prepares a list of items which it expects to take into the field. Perhaps it should not be surprising to find the final list is quite different from the list first submitted. Such items as transit, level, surveyor's tape, rod, and appurtenances are deleted and such items as compass, Abney, carpenter's tape, plumb line, chalk, folding rule, quadrille-ruled sketch pad, and camera are added. At the planning stage, "one half-day in the field" and "six men per car" are more convincing as arguments for going light than are arguments in favor of using a rule and plumb bob rather than a transit and tape. The student, however, has an opportunity to *learn* from his experience.

At the site the assignments and plans of each squad are checked briefly and the instructor makes last-minute suggestions to expedite the work. Then, as the work progresses, the instructor makes the rounds and directs attention of the men to matters of function, detail, and scale—in short, as they measure and record details about the structure, he helps them "get a foot in their eye."

After about two hours' work the class assembles for very brief reports by each squad leader covering information gathered and items of particular interest. Members of other squads and the instructor point out omission of essential data and offer other helpful criticisms. After each squad leader has reported, the squads complete and check their respective assignments.

Observations of the behavior of a plate girder bridge as locomotive and cars pass over it also involve teamwork. Some students measure deflections while others record data about the locomotive and car loadings. Later these observations provide a basis for estimating the live load and impact stress in the girder by simple application of the geometry of flexure to a girder whose section varies to maintain substantially the same limiting fiber stress at full load. Here the student can recognize that "f/Ed is proportional to M/EI" and that the

former quotient is far more comprehensible than the latter in this case.

The report of the field trip comprises the layout to an assigned scale of plan, elevation, and section of the portions of the structure covered by each squad. Adequate dimensions, notes, and title information are essential elements of each squad's report. An assistant (and sometimes the students themselves according to plan) makes a composite tracing in pencil of the entire structure and each student is furnished with a print. This indeed is the student's bridge—and the class is eager to complete a similar assignment for a through truss bridge with less intimate direction from the instructor.

Unfortunately field trips ceased with dwindling classes and restrictions on automobile travel. Photographs can be helpful substitutes provided they are used as more than pictures. Daily newspapers and popular magazines (not to mention the obvious engineering and construction journals) publish photographs which are timely and which can stimulate the student's appreciation of size, proportion, form, and function. Analysis, rather than synthesis, of perspective in a photograph showing people or things whose sizes are known approximately, offers much which can be stimulating to the student—and to his engineering teacher. Photographs and other visual aids are not being used in engineering instruction beyond an insignificant fraction of their potential usefulness. Photographs of local work are helpful in providing the student with a scale and a basis of evaluating the usefulness of photographs to him. What instructional material is everywhere around us if we could only recognize it! What effective use could be made of film strips to make dusty plan files *live* by bringing plan and photograph of the actual work together on adjacent frames for projection by the students in a film library! Could not a series of dated construction photographs help to give the student a basis for visualizing—and perhaps even estimating roughly—materials, plant, men, and progress which affect the cost of that particular construction work?

Teamwork in the Drafting Room.—Teamwork among students is as important in drafting, analysis, and design courses as it is in the field inspections which we have discussed. Too often the teacher in engineering applications puts the entire class through the same problem in all its details—and sometimes repeats that problem year after year. In courses of the supervised-work type where the instructor has two or three consecutive hours' contact with his students, we feel there are many advantages in organizing the class much as one would organize a small engineering staff. Let us consider further some possibilities of teamwork in analysis and design and use another structural engineering example:

Once the fundamentals of analyzing a statically indeterminate truss have been established, the students are eager to try their hands at applying them. Textbook examples are often cut to the proportions that one student can complete a problem in a reasonable time—and the problem is often quite academic. With a class of half-dozen or more students, why should each one do the same work on an academic problem when, by careful planning and assigning of jobs, they can work as a team in analyzing some structure which has been designed, built, and reported in the engineering literature?

With teamwork, even a small class can pool its efforts on a problem such as the analysis of live load stresses in the Sciotoville bridge to the end of determining—

1. Live load stresses in members of a parallel-chord panel.
2. Live load stresses in members of a non-parallel chord panel.
3. Angle changes along the load line at two or three panel points corresponding to an assigned center pier reaction.
4. The influence line for center pier reaction, drawn out of the information assembled in (3).

The atmosphere of the practical and the rivalry of several squads to complete their assignments on schedule and in good form instills a spirit among the students which makes the teaching of engineering applications a pleasant assignment indeed.

This teamwork among squads places a premium on systematic, orderly work which can be checked quickly by any other member of the class. Here our specifications are uncompromising. A student must show on each sheet of computations, the subject, his name, and the date. Students are required to work directly on quadrille-ruled paper and copying from scratch-paper is effectively stopped. A statement of the problem, workman-like sketches complete in all essentials, and systematic arrangement of numerical computations is established by example, by suggestion, and by direction as needed. With the view to keeping the student's mind on the physical problems, arithmetic and geometry are used as tools of *computation*, although algebra, trigonometry, or higher mathematics may be used as tools of *analysis* in setting up the problem.

At the outset, many students (and some teachers) feel that time can be saved by taking short-cuts which may combine into a single operation several intermediate steps. When the student (or the instructor) has the responsibility of checking another's computations he is more likely to acknowledge the merit of straight-forward systematic work which keeps the physical problem constantly in mind over the work of the unsystematic genius who may preface his conclusion with the academic "it is obvious that. . . ."

Conclusion.—These examples in the field of structural engineering, have their obvious parallels in other branches of civil engineering, in hydraulic engineering, in sanitary engineering, in transportation engineering, and in the plant and operational phases of engineering construction. Likewise, they have their parallels in other major divisions of engineering at the college level.

Thus, in teaching courses in engineering applications, we would emphasize the importance of teamwork among squads of students and of purposefully planned work as a team activity between instructor and student. Probably nothing is more difficult to learn or to teach than the power to observe things of significance in full scale and in balanced proportions. We feel that carefully organized field trips under alert supervision will do much to accomplish that end. Photographs and visual aids offer possibilities for further exploration and effective use. Teamwork in analysis and design involves adherence to standards of performance which should be practical, reasonable, and rigidly enforced. Given the broader assignment, it has been our experience that students will accept the responsibility for carrying out the details—and they will perform without minute supervision.

Discussion

By L. E. GRINTER
Illinois Institute of Technology

I am not sure whether my remarks are a discussion of teaching methods in engineering analysis or in engineering applications. They will naturally bear on my own experience which is rather heavily weighted toward the design of various kinds of structures. But since every design course turns out to be about fifty per cent analysis, that is, if it is a really good course in design, I am not sure whether my thoughts are entirely related to the subject matter of the paper by Professors Mavis and Edwards or whether they apply to the paper of Professor Teare.

It has always been difficult for me to separate the subjects of analysis and design and, in fact, I think they are well taught together. Too frequently, their separation leads to an artificial point of view. Actually, we are interested only in design, analysis being a necessary evil to be shortened, or eliminated if possible, but which actually consumes about one-half of our time. Analysis can be taught entirely by lecture and recitation, I suppose, but to me it has always been significant that students who have found analysis and basic theory uninviting in the classroom quickly change their minds when confronted by a practical design problem of their own choosing which requires such knowledge for its solution. The design room is a great place for teaching theory under favorable relationships between student and teacher.

I have never tried the group plan of working out design problems. No doubt it stimulates a coöperative frame of mind which has its counterpart in the subdivision of work in a practical engineering office. Perhaps that is why I have approached the teaching of design from another direction. My thought has been that the influences of the world are all at work remaking people to "fit in" with things as they are. Every time anyone has a new idea or a desire to try his wings, he has to combat the frame of mind developed by coöperatively fitting in with group action. Perhaps, then, it is not our job to emphasize the usefulness of group action as much as the importance of individuality since our students will only retain a small residue of individuality after a few years anyway. Let us not fail to stimulate it in the first place, else it may never develop.

My feeling is that design courses should meet two requirements in addition to those that are never questioned. These are first to teach "design for function" and second to emphasize the "individuality of design." Design for function starts back with the original desire for the structure, plant, or machine, and takes into account physical, social, psychological, economic, artistic, scientific, and practical influences. No doubt the teacher will do this job badly at first and may never excel at it for it is a broad assignment, but the student needs early and repeated exposure to the study of function if he is to become a real engineering designer.

The individuality of design may be taught both directly and indirectly. Many machines will serve a given pur-

pose, perhaps not equally well, but competitively as may be seen in any free market. Hence, there is always chance for improvement if the designer is sufficiently informed and clever. This can be taught by having each student work out a design of his own choice and by encouraging him to search for improvement over the text-book examples. There is remarkable stimulation to the student in choosing his own major design problem (under guidance of course) and in carrying through its functional design as well as the detailed design.

It may seem that this procedure would load the teacher with an impossible job of correction and grading. However, by insisting upon systematization, the design notes and drawings can be graded as quickly as a single standardized problem since the teacher soon learns to judge correct proportions which are turned into unreasonable relationships by most errors. Knowing that his design is unique, the student does not waste his time copying or getting excessive help or trying to make answers check with probable results. He too learns to check his design results by common sense and by thinking as the authors rightly emphasize in "full-scale and in balanced proportions."

A rounded engineering education includes the development of individuality, of ability to coöperate, of intensive specialization, and of a broad understanding of engineering problems. One teacher will emphasize one characteristic while another chooses a different direction of emphasis. One student reacts to one teacher's methods, another student develops in some other class. Studying some fifty courses, the student fortunately experiences many methods of teaching. Our real problem is to get the best possible teachers and the best possible students together. The system of instruction may be left to the judgment of teachers and of departments.

By A. R. STEVENSON, JR.

As Dr. Teare says, the engineering method can be used in any given course. He is right that there is an added benefit from a general course in engineering analysis which bridges the various vertical compartments in which scientific studies have been segregated. It gives an opportunity to synthesize all the engineering courses into one fundamental science, based on the law of conservation of energy and a few special definitions and observed laws for each branch. Many of these definitions and observed laws, which at first glance appear totally different in the various branches of engineering, are better understood when the analogies between different branches of engineering are pointed out.

In engineering we very seldom have a problem which can be segregated into one narrow compartment of science. Many problems which at first sight look like electrical problems, cannot be settled finally until other things like heat transfer have been investigated.

Just for the fun of taking exception to at least one thing which Dr. Teare said, I might quote one of his sentences: "The procedure of solving problems may in many cases be summarized as *first*, the expression of a

given situation in terms of a mathematical equation. . . ."

Since Dr. Teare and I have both been associated with President Doherty, I am sure Dr. Teare will agree with me when I say that he has not started at the very beginning in this summary.

When we first started the General Electric Advanced Course in Engineering on September 6, 1923, Dr. Doherty gave the first lecture. I have a copy of that lecture and I would like to quote from it.

> The *first* step in the proper attack of a problem is to picture in your mind the physical set-up of the problem. Get a physical conception of the problem; and then, try to set down as accurately as possible what the conditions are which must be satisfied. If you don't you will be hopeless. You might as well stop working on them, because you'll never get to the end. There's only one way I know of in which such conditions can be set down, and that is to decide what physical laws control the situation. If you know that, it is certainly easy to set down the conditions that have to be satisfied. You can set them down in English. You have a given problem and we'll say that Newton's third law of motion is the determining factor. You can say, in English, that the sum of all the forces acting on a body must be zero. Suppose the problem involves some such set-up. The next step is to set that condition down mathematically. Usually this involves differential equations. A differential equation is simply a system of shorthand for making the same statement mathematically as we have made in English. All forces acting on the body are equal to zero. It is possible to write a differential equation which says the same thing. From then on until you get the solution, your process is purely mechanical. Anybody can do that. The difficult thing to do is first to set down in the equation the condition which must be satisfied. Thus, state the problem, and the second thing is to tell whether the answer is right when you get it. That's often more difficult than the first. That, in general, is the point of view that you have to get in mind before you can successfully go at these things.

You will note that Dr. Doherty, 21 years ago, listed several things which must be done before the expression should be written in terms of mathematical equation.

I am glad that Dr. Teare has emphasized the choice of problem. It would be a fine thing if many of the problems could be ones which the professor is currently solving in connection with consulting work. On the other hand, they must not be so difficult that the professor is forced to show the students every step.

Dr. Teare mentions the high level of interest shown by the students in the General Electric Advanced Course and suggests some reasons for this. Perhaps there is another one. We use student supervisors who have taken the class the year before. To them, the subject is still new, and they all testify that they learn twice as much the second year supervising the class as they did the first year while taking it. The result is that they have unbounded enthusiasm. They are high-grade men picked for their leadership ability and their enthusiasm is contagiously imparted to the class. They would not have this enthusiasm unless we gave them freedom and responsibility.

I do not know, but I imagine that in many colleges the curriculum is taken too seriously and laid down in too meticulous detail with the result that the instructors do not have suf-

ficient freedom to show their own creative ability in handling their classes.

We feel that genuine enthusiasm is of great importance. We feel that one of the best ways of creating enthusiasm is to make a man responsible. A man does not have the right kind of responsibility when he simply carries out meticulous orders. If the professor tells the instructor, "You teach this text book just as I wrote it twenty years ago, exactly as I taught it!!!," the instructor's enthusiasm is killed at the start and he cannot impart any enthusiasm to his class.

I am glad that Dr. Teare has mentioned free hand sketching. I believe that this is something which every young engineer should be able to do. I also believe that it should be coupled with a thorough course in descriptive geometry which includes shadows and perspective. These things, thoroughly understood and practiced, should improve a man's ability to visualize and this should be of assistance in developing mechanical ingenuity.

Design problems should be simple enough so that the student can solve them completely from fundamentals without using empirical handbook information. Rather than to design a complete direct current generator in all its details simply using the professor's knowledge with regard to air gap reluctance, heat transfer from coils, etc., there would be more education in designing the simplest type of lifting magnet, completely working out all details, such as air gap reluctance obtained from free hand flux plots, and heat transfer coefficients derived from experiments which the student should carry out himself in the laboratory.

There is one other piece of advice I would like to give with regard to solving problems. I believe that one should attempt to guess the answer before starting a long mathematical calculation. W. L. R. Emmet used to call this "proportionate thinking." In guessing answers one is not likely to be more than 100 per cent wrong. Whereas, in a long mathematical calculation one may lose two or three decimal points and be 1,000 per cent wrong. If the results of the mathematical calculation do not give an answer of the same order of magnitude as the original guess, the comparison raises a "red flag" which causes one to look for errors. Every answer should be checked by common sense.

I remember the first year that I was teaching the Advanced Course. While we were leading up to the theory of electrical fields, we did some problems in gravitational fields. We gave the class the weight of the moon and the weight of the earth and the distance between. We asked them to calculate how fast the moon must travel in its orbit to prevent it from falling toward the earth. One of the best students in the class turned in the solution with the answer in miles per hour. We criticized him because he had not expressed it in days per complete revolution which could have been checked by common sense. Expressed in these terms, he had the moon going around the earth eight times a day, which was quite obviously wrong.

There has been a great deal said recently about intuition. I believe that guessing the answer first helps to develop the intuition. A friend of mine who used to sell cattle said he always made a point of guessing the weight of a steer before driving it on the scales. After doing this for sometime,

it was quite surprising how accurately he could guess the weight after a single intuitional glance at an animal.

Some of the best engineering mathematicians whom I have known, like C. A. Nickle and E. G. Keller, have been able in many cases to guess the solutions to complicated mathematical problems which would later take weeks or months to work out and prove in detail. Therefore, I believe that guessing the answer and checking these guesses will benefit the student in developing both common sense and intuition. I like Mr. Emmet's phrase, "proportionate thinking."

The few foregoing remarks are my only comments on Dr. Teare's paper, which I believe covers an important subject very well.

A Manual of Graduate Study in Engineering

Prepared by

COMMITTEE ON GRADUATE STUDY—SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION
1945

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Foreword

In the summer of 1942, the Committee on Graduate Study was formed and asked to study the trends in graduate education in engineering and to report its findings to the Society. After three years of continuous study, the Committee herewith presents its report in the form of a manual which analyzes objectives and procedures in engineering graduate study and makes recommendations concerning good practices and suggestions for improvements. For the reader's convenience, the subjects discussed are summarized first, but a careful reading of the entire manual is necessary to understand the suggestions and recommendations because many of the subjects discussed are rather philosophical in their nature.

The Committee has leaned heavily upon the 1935 survey of Graduate Work in Engineering, made by the United States Office of Education * and analyzed with the assistance of the S.P.E.E., but there has been no attempt to extend that survey or to reproduce it here. The 1935 survey contains supplementary information of great value since the disturbance of graduate education brought about by the war leaves it still the most authentic picture of normal or pre-war practices in engineering graduate study.

The Manual is no rigid set of specifications that are expected to determine inflexibly the course of graduate education in engineering. The Committee recognizes fully that great graduate teachers and the best graduate students will grow most effectively under a lack of petty restrictions and that graduate work is adult education primarily for superior minds. However, all graduate students are not superior and great graduate teachers must go through the period of their own development. It was thought, therefore, that the manual should be as specific regarding good practices and suggestions for improvement of graduate education in engineering as the wide variations to be expected in this field would permit.

* W. C. John and H. P. Hammond, "Graduate Work in Engineering in Universities and Colleges in the United States." Bulletin 1936, No. 8. U. S. Department of the Interior, Office of Education.

Summary of Conclusions and Recommendations Regarding Graduate Study in Engineering

1. Objectives

If oversimplification is permitted, the objectives of graduate study can be stated as the development of men able to experiment or otherwise to collect, appraise, digest and analyze evidence, and trained to prepare a clear statement of the findings. Such studies should advance intellectual honesty, imagination and courage.

2. Organization

Graduate and undergraduate instruction benefit by close contact for they are complementary functions that may be performed effectively by the same teacher, but they are sufficiently distinct in their objectives to be differentiated through certain phases of administration such as faculty designation, and budgetary control.

3. Transitional Studies

Experimentation with research and development options for exceptional undergraduates, omitting certain courses from the junior and senior years to make room for advanced study in mathematics, science, and engineering analysis, and for an introduction to the methods of research, seems in order as an integration of undergraduate and graduate education.

4. Graduate Faculty

The development of a graduate faculty requires administrative encouragement of professional objectives, of research and scholarship as evidenced by a sympathetic understanding of the scholar's problems, appreciation of his accomplishments, financial support for his work and an adequate personal reward.

5. Admission Requirements

Fuller realization is needed that only students who rank in the upper quarter of the graduating class are likely to become strong candidates for an advanced degree. Devices such as trial registration, entrance examinations, preliminary examinations for the doctorate and others may be used to uphold the proper standards of the graduate school.

6. Degree Requirements

Formal requirements for advanced degrees in engineering are properly set by each institution although there is general agreement upon one academic year of residence study for the master's degree and three years for the doctorate. More detailed formal requirements will be needed to guide the average student, but it should not be forgotten that the graduate school remains the province of the superior mind.

7. Major, Minor and Research

The "major" should be devoted to one field of study and should include the thesis research, but departmental lines should not be restrictive in the selection of courses or teachers. One "minor" (for the doctorate) is recommended in a field of science or engineering clearly separated but contributing to the strength of the major study. The length of the doctorate residence makes two minors permissible.

8. The Thesis

A thesis is recommended for all advanced degrees in engineering. For the master's degree, it is considered to represent training in research or in the more scientific phases of design or development. For the doctorate, the thesis is considered as evidence that a

candidate has made a contribution to science or to engineering knowledge.

9. Language Requirements

As an alternative to the usual required "reading knowledge of French and German" for the doctorate, it is recommended that evidence be accepted that the student has command of one foreign language which he has used effectively and extensively in relation to his thesis.

10. Mathematics

Graduate study in engineering emphasizes the mathematical or scientific approach to the solution of technical problems. It is accordingly recommended that the master's program should be strengthened by requiring one or more courses in mathematics beyond a first course in the integral calculus and that the doctorate should commonly include a minor study in advanced mathematics.

11. Examinations

Greater emphasis should be placed upon comprehensive examinations of the combined written and oral type for both master's and doctor's degrees. These serve not only as a yardstick to measure the attainment of the student, but also as a rather tangible expression of the objectives of graduate study and as a means of bringing them to the attention of students and faculty.

12. Undergraduate Courses

Undergraduate course work should be accepted for graduate credit only when taken in fields for which the student is not expected to have the prerequisites for full graduate study and then only when taken as an approved part of a graduate study program. Also, it is recommended that no more than twenty-five per cent of the program be permitted in undergraduate courses.

13. Non-technical Studies

The recommendations in 12 above are also to be applied to graduate studies in economics, political science and administration which may be proper optional studies for certain fields of engineering.

14. Evening Classes

Evening graduate study is accepted to be of the same significance as graduate study in the day. Its coöperative features for maintaining close association with industry are recognized to be of importance.

15. Coöperative Programs

Coöperative graduate study has the same advantages and disadvantages as coöperative undergraduate study. It is an important alternative to regular full-time graduate work. Careful integration of classroom study with work in the design office or laboratory is an opportunity to improve the standards of coöperative education in the graduate field.

16. Sponsored Research

Sponsored research of a clearly fundamental nature in residence has the same educational value as institutionally sponsored research and is the only kind of sponsored research acceptable for the doctorate thesis. Even then, it is recommended that the time spent on organized project research be reduced one-half in determining residence value. For the master's degree greater freedom is suggested and some graduate credit is acceptable for industrially sponsored development work when placed under qualified educational supervision.

17. Industry Institutes

Graduate institutes serving a single industry face the problem of domination by that industry which may result in the use of vocational standards for measuring graduate-study objectives. This will be combatted most effectively when such institutes are closely associated with colleges or universities which foster other graduate study in science and engineering.

18. Foreign Students

A semester of orientation into American graduate study is recommended for the foreign student who needs supporting work in English, in laboratory science, or in practical engineering courses. These are common deficiencies.

19. Student Guidance

The most practical advice to brilliant undergraduates is to enter the graduate school immediately after graduation before there is a loss of facility in the use of mathematics, physics, and the theoretical tools of engineering. Graduate students should be treated as adults, but they still need guidance in the importance of using the library and of setting up, stating, and solving problems.

20. Teaching Loads

It is recommended that teaching loads be based upon an analysis of total instructional hours including class hours, preparation, grading, and counseling for both graduate and undergraduate courses. Until better information is available, it is recommended that graduate and undergraduate courses be given equal teaching value based upon class hours. Some evaluation of the equivalent teaching load involved in direction of thesis research should be made.

Graduate Study in Engineering

(1) Philosophy and Objectives

The Purpose, to Search out, Guide and Form

a mind nimble and versatile enough to catch the resemblance of things and at the same time steady enough to fix and distinguish their subtler differences; as being gifted by nature with desire to seek, patience to doubt, fondness to meditate, slowness to assert, readiness to consider, carefulness to dispose and set in order . . . that neither affects what is new nor admits what is old, and hates every kind of imposture . . . a kind of familiarity and relation with Truth. . . .

The Acknowledged Instrument Being Study

Studies serve for delight, for ornament, and for ability. Their chief use for delight, is in privateness and retiring; for ornament, is in discourse; and for ability, is in the judgment and disposition of business. For, expert men can execute, and perhaps judge of particulars, one by one; but the general counsels, and the plots and marshalling of affairs, come best from those that are learned—for natural abilities are like natural plants, that need pruning by study; and studies themselves do give forth directions too much at large, except they be bounded in by experience.

Read not to contradict and confute, nor to believe and take for granted, nor to talk and discourse, but to weigh and consider. Some books are to be tasted, others to be swallowed, and some few to be chewed and digested. Reading maketh a full man, conference a ready man, and writing an exact man. . . .

Histories make men wise; poets witty; the mathematics subtle; natural philosophy deep; moral, grave; logic and rhetoric, able to contend: "Moral habits are influenced by studies"—nay, there is no stond or impediment in the wit, but may be wrought out by fit studies. . . .

Francis Bacon

Graduate study in engineering is a part of the general process of education. We are trying to prepare a whole man to live a full life in a whole world. This statement is too general to be very useful in formulating curricula or setting standards for degrees, but it is important not to forget such ideals. There are important differences between undergraduate and graduate students, but the difference is more one of developing personal responsibility and the implied need for scrutinizing evidence than one of overall objectives. At times study of a subject on the graduate level should proceed much less rapidly than on the undergraduate level because we must take time to examine assumptions critically; at other times it should proceed much more rapidly because the undergraduate studies have removed some of the obstacles to education.

The Devices of Graduate Study.

In undergraduate work we have time to give individualized training only to a limited degree; graduate work should be highly individualized and the student should be put more and more on his own responsibility until finally he has a more profound idea of what is meant by accuracy of statement and learns to judge with humility. Too much emphasis on discussion instead of analysis produces a man who can argue all sides of questions but is so trained that he cannot settle anything; and yet too great elaboration upon the analytical method may produce a dangerously erudite and clumsy pedant. We must and can reconcile these extremes but there is, in this regard, much room for improvement in our graduate teaching.

It has recently been said, "In research, there are no standards." This comes near the truth in graduate study; but here again "all generalizations are false, including this generalization." The general objectives are to indicate the broad scope and intimate interrelationships of fundamental and practical knowledge; to teach the importance of accuracy and precision in securing evidence; to give practice in analyzing evidence, drawing conclusions, and presenting these results concisely and clearly; to develop intellectual honesty, imagination, and courage. To do this requires a well balanced individualized curriculum and a faculty presenting a diversity of personality, experience, and outlook. In graduate education, as in a well chosen library, "much should be tasted, a part may be swallowed, some must be thoroughly chewed and digested."

The Student, the Institution, and the Public

Graduate study in engineering may be considered from the points of view of the public, of the institution concerned and its faculty, and of the individual student. These are intimately related and probably no one of them is considered exclusively by any American faculty; from any of these points of view it is in the end the trained student that is valuable to the world.

Certainly graduate study in all fields should be sanely directed toward the interests of the community; how large this community should be considered to be—state, nation, international—depends upon the institution and the nature of the study.

For the institution, graduate work performs several related functions. It forces the faculty to reëxamine critically the fundamentals of knowledge, because no honest graduate teacher can rest long; it furnishes a relatively unin-

hibited field of experimentation where methods of thought and instruction may be worked out for use in undergraduate courses; it raises the general level of intellectual thought in the academic life of the university. The investigations may and sometimes do enhance the reputation of the institution in the scholarly and professional world, though this incident of graduate study is often overstressed; it is generally the by-products of faculty growth and improvement of teaching techniques that are valuable.

Idealists may argue that we should consider the student alone. But if funds are not available for equipment and faculty, good graduate work may be badly hampered and subsidy from industry may be necessary. Although this statement implies no approval of the use of subsidized graduate students as a cheap labor supply to do petty research chores for industry, it is reasonable to expect a student to conform under faculty direction to the needs of the industry that is subsidizing his study and also to give all that he can, intellectually and personally, to the academic world of which he is a part.

The Analytical Method

Evidence must be secured by experiment, or otherwise collected, intelligently appraised, arranged and digested, interpreted, and then presented with clearly stated conclusions. To collect the evidence involves knowledge of the literature of the field and of methods that might furnish useful data whether original or from records. Important tools are analysis and synthesis, mathematics, experiment, observation, sampling, and common sense. To appraise the evidence intelligently involves knowledge of the dependability of the sources and requires independence and courage in forming judgments; it requires the scholarly accuracy that comes only from arduous training. To arrange and digest evidence demands practice, assisted by study of good reports as models. To interpret involves imagination controlled by logic and analysis, a well developed sense of proportion as to the relative importance of the sources, broad knowledge of the field of study and of the general fields of science pure and applied; some say that it also requires fast and prayer.

Reporting Findings

Students of engineering develop as they learn to compose and present reports or prepare and explain designs. This statement may be accepted without any commitments as to the nature of the thesis or even whether a formal thesis is required at all; commonly reports, investigations, and designs of several types are needed. To prepare these the student must be able to state the problem that he proposes to study, to assemble pertinent evidence, and to present and sum up this evidence.

Presentation of the evidence requires a mastery of technique along with good manners and good taste. The engineer uses four methods to present evidence: *graphical* — drawings, pictures, sketches; *statistical* — charts, tables, pictorial charts; *symbolic* — mathematics in the broader sense of the term; *verbal* — the written or oral report. Drawings or charts that are not readily comprehended cannot be excused; bad spelling or diction or punctuation, labored style, lack of unity or coherence or emphasis are serious defects; documentation and general editing should be uniform and should adhere to some reasonable standard; brevity is always desirable. Most students think that

the difficulty is to secure the evidence; interpretation and presentation too often receive the barest minimum of attention.

Clearly the summing up is important; the student will learn more and more during the next forty years how difficult it is. A brief and clear summary may be the crowning glory of a good engineering report, but a good summary is very hard to write.

Asking Questions

It seems so simple and is really so difficult to state a question in engineering in a form amenable to investigation. One of the most important things for graduate students to learn is the great value of men who ask significant questions leading to problems that can be investigated by available techniques. The list of titles of graduate theses is pretty drab to an experienced man; this is probably unavoidable, for we must learn to creep before we stride. Nevertheless, graduate students should learn that the conventional question is often not the important question at all.

The discussion above is immediately applicable to reports and research investigations, but with obvious changes it applies to designs, which involve a synthesis of such reports—to make a design we must finally make decisions correlated to the evidence. It is well then for graduate work to end with the study of design, for engineering research, whether fundamental or extremely practical, is but a step along the final road to the engineering office where that process of synthesis called design takes place.

(2) Organization and Administration of Graduate Study

The organization of graduate study can proceed along either of two opposite courses—the establishment of a separate institute of graduate study, or the integration of the undergraduate and graduate faculties.

The Separate Institute of Graduate Study

A few graduate institutes will no doubt develop with the primary objective of fundamental research in science and engineering along with graduate instruction. The realistic difficulties of obtaining adequate financial support without appreciable tuition income will probably limit to a small number the institutions of this nature. Nevertheless, a few well endowed or publicly supported graduate institutes would set high standards to be emulated in the graduate programs of our engineering colleges. If such institutes could develop consulting or research services to industry without compromising their basic objectives of fundamental research and graduate study, the problem of financial support might be eased. However, if support is limited to one industry, the problems inherent in the industry institute (section 17) are likely to arise.

The Integrated Faculty for Undergraduate and Graduate Instruction

At present, most of the graduate teaching in engineering is carried on by faculties having the primary responsibility of undergraduate instruction. The benefits derived from close association of graduate and undergraduate instruction should be preserved, but graduate instruction as an overload for undergraduate teachers has no merit or justification. The benefits derived from close association of graduate and undergraduate instruction are: (*a*) Undergraduate students

may be led progressively into graduate work as discussed more fully in section (3). (*b*) Young teachers have the example continually near them of the successful and distinguished graduate teacher whose greater freedom of activity is a reward that has a wide appeal. (*c*) The professional objectives established in the graduate school influence faculty and student points of view concerning undergraduate instruction, resulting in improved standards of undergraduate work. (*d*) The emphasis upon research, which cannot be neglected in the graduate school, vitalizes instruction at all university levels.

Organization for an Integrated Faculty

Undergraduate instruction is almost universally placed under a dean of engineering or of technology with departmental directors responsible for the conduct of the work of individual curricula. With a single faculty there is a continual strain between those who would emphasize undergraduate instruction and those who would emphasize graduate study and research. The common arrangement of a graduate school functioning under a dean who has neither faculty nor budget but is given authority to set standards of graduate student performance is not a solution to the overall problem.

If we admit that objectives in graduate and undergraduate work are complementary but are still sufficiently different to require individual emphasis within the faculty, it becomes evident that they are best integrated through close physical association but differentiated through certain phases of administration such as faculty designation, and budget control. The department directors are naturally given full responsibility for undergraduate and graduate instruction and it is clear that in most departments every faculty member should be conducting at least one undergraduate course. The normal budget should provide salaries, equipment, and supplies for maintaining the complete undergraduate program.

The Graduate Faculty

The graduate function in engineering may be more effectively conducted by a designated graduate faculty both a part of but separated by special appointment from the undergraduate faculty. It is recommended that there be supplementary salaries for those who have become sufficiently distinguished in professional activities and research to be chosen for membership on this faculty, and a special budget for research equipment, supplies, and subsidiary services to research professors and graduate students. If the budget for the graduate function is separated from the undergraduate departmental budgets, there will be every reason for departmental directors to encourage research and graduate study within their departments since this work adds to the services and luster of the department without reducing the expenditures upon undergraduate instruction. When teachers are placed upon the graduate faculty, their undergraduate teaching loads should be limited so that there can be no reason for constricting graduate instruction and research to provide additional undergraduate instruction.

The graduate faculty should be responsible for all graduate instruction and should include research professors and others who have been selected for their professional work and for their contributions to the conduct of graduate study. It is important, however, that younger members of the teaching

staff should be encouraged to associate themselves with these graduate teachers for the purpose of preparing and giving special lectures before graduate seminars or for supervising laboratory phases of thesis research under the direction of a research professor.

Subsidiary Services

Experience has long demonstrated that the difficulties of conducting effective research are unnecessarily great in most educational institutions. The researcher who uses only paper and pencil is looked upon as a fortunate person. Eminently successful research organizations, whether in industry or education, make research as easy to accomplish as possible. The necessary subsidiary services for laboratory research in engineering, physics, and chemistry are (*a*) excellent shop services on a generous scale (*b*) the help of a draftsman (*c*) photographic, photostatic, blueprint and stenographic help when needed (*d*) administrative, purchasing, and accounting aid with the minimum of red tape (*e*) library service especially adaptable to the research worker. These subsidiary services add more to the accomplishment of research than any comparable expenditure of funds. They must be set up, however, as freely available services because, if they are primarily organized for industrial research or for the undergraduate program and only secondarily for fundamental research and thesis investigations, accomplishment in the latter direction will be very greatly restricted. Research workers are not interested in or competent to fight continual battles against the organizational system of the institution. Research needs cultivation and thrives on friendly coöperation.

(3) Integration of Undergraduate and Graduate Education

There has been little organized effort to acquaint the best undergraduate students with the objectives and rewards of graduate study. Nor has the usual engineering curriculum offered the undergraduate student stimulating association with graduate students or with research. The period of undergraduate study has too often been an end in itself—a practical education planned to fit the graduate for an introductory position in the practical work of engineering.

Majority and Minority Groups in Engineering Student Body

For a majority of undergraduate students, the typical engineering curriculum which has received E.C.P.D. approval provides a satisfactory stimulation. It balances work in the art of engineering with a study of the basic engineering sciences, and includes some leavening through the humanities and the social sciences. It properly restricts the specialist in his desire to teach the more theoretical phases of design because of the limited capacity of the majority of students to master such mathematical subjects as the advanced phases of mechanics, heat transfer, fluid flow, thermodynamics, and electrical wave phenomena.

For a small minority of engineering students, these latter subjects are of the greatest interest. Such students have usually proved themselves to be superior scholars in mathematics, physics, and the more theoretical subjects of the junior year, although some have distinguished themselves at laboratory experimentation instead. To remove these gifted students from the lockstep of the fixed undergraduate curriculum

by optional studies should contribute toward their intellectual development and therefore toward the production of research and development engineers and of those specialists who handle the higher phases of engineering design.

Research and Development Options

Experimentation, for selected students in substituting advanced scientific study and an introduction to the methods of research for standardized courses from the junior and senior years seems in order. Experiments in selecting such students and in evaluating the results achieved will be watched with the greatest interest. It seems doubtful whether an overall revision of less than one full semester of eighteen credit hours of study could prove very significant—although the work of any Research and Development Option should probably extend over more than one semester, perhaps over as many as four semesters.

The objectives to be achieved by special instruction of a carefully selected group of students are: (*a*) To encourage students of unusual capacity for scientific study to greater intellectual effort by giving them more freedom in the choice of courses, of seminar study, and through individual contact with research professors. (*b*) To stimulate selected students to attend such graduate courses as their development fully justifies. A few courses for graduates and advanced undergraduates will serve a useful purpose, but the objectives of graduate study cannot be met by placing most graduate courses on that basis. (*c*) To permit certain students to work with a research professor upon either theoretical or laboratory research. The professor must, however, understand and accept his responsibility for directing the student's educational progress and not use the student only as a research assistant. (*d*) To admit those students who show exceptional growth during the early phases of this procedure as graduate students before the award of the bachelor's degree if their objective of study for an advanced degree has been sufficiently established.

Objectives and Problems of Individualized Study

The dangers inherent in this proposal are evident. The mere selection of the proper students requires effort and careful analysis. The freedom of selecting courses and seminars and of substituting laboratory research or independent study for courses in the regular curriculum will be abused if it is not guided thoughtfully. In so far as less formalized study is substituted for course work, the problem of examination for credit becomes important. If overemphasized, this plan could lead to the feeling among students that the standard engineering program was really substandard with resultant excessive numbers of candidates for the research and development options. On the other hand, unless the plan is properly organized and presented to the students so that its objectives can be readily understood, it may be labeled "highbrow" and fail completely. Finally, there is little question that some breadth of education must be sacrificed to achieve the specialization suggested here since a lengthening of the period of study for the bachelor's degree is not recommended.

Summary

The production of engineers educated in basic science and the more theoretical phases of engineering and

trained in the procedures of research is an objective of the greatest significance. The demands for men with advanced degrees in engineering have increased more rapidly than the supply so that students with bachelor's degrees are taken directly into research and development organizations. More scientific specialized training at the undergraduate level will aid in solving this problem by offering better preparation for those who will leave the undergraduate college and go directly into research or design and development work, and it will also encourage more students to continue their education in the graduate school by eliminating the present sharp line of demarcation between undergraduate and graduate study for selected students.

(4) Development of a Graduate Faculty

Great teachers are rare, great graduate teachers very rare; good teachers are not too common, but it is probably as easy to be a reasonably good teacher of graduate students as of undergraduate students—perhaps it is easier. Mediocrity in teaching is always at hand and if dominant is always dangerous. Perpetuating and perfecting techniques is a function of graduate training, but it is an incidental function, not a primary objective; the importance of it depends on several factors, one being the field of study. Speculation is certainly a function of graduate study, but too much attention to it produces that unfortunate product who can discuss all questions and answer none, win all arguments and lose all decisions. We must produce thinkers who are doers as well.

A graduate faculty needs a few great teachers, some good teachers, and can use mediocre teachers, but not mediocre engineers, for some of its work. From the point of view of the general faculty, it is probably well, and some think it important, that all members of the staff take an active part in the graduate program. But this does not mean at all that every teacher should be in charge of a graduate course; within limits, graduate courses should be few rather than many and should be placed in charge of teachers having some elements of greatness. Here, of course, administrative difficulties arise, since those who are mediocre are often surer of their own greatness than are great teachers; also, the man thought to be mediocre may grow and the great teacher may lose his vital spark. The point at least emphasizes the danger of active administration of graduate faculties by mediocre scholars.

A Diversified Faculty

Graduate faculties should not be too homogeneous. The students should be blown on here by many winds of doctrine so that they will not later be too easily blown about by them. Rationalist and empiricist, mathematician and historian, formalists and those who care little for convention, all have a place provided they do not insist too violently that there is no place for the others.

A graduate faculty must grow and then must keep on growing; this is true of the individuals and of the organism. The recluse is common in this environment, but it is always unfortunate that he is a recluse. Growth comes from exchange of views—of many views, of discordant views. The growth of honest interest in knowledge should be so active that petty vanity or smug pedantry do not unduly thrive;

mutual admiration societies are rarely vital.

A great graduate teacher must be honest and must be active in research which means that he must with honesty and humility seek truth and pursue it, he must be intelligent and well informed, he should be broadly educated and have had experience that is varied even if partly vicarious. He need not be popular or handsome or witty or even famous, but he must somehow inspire students to emulation and to subsequent independent production.

Encouraging Faculty Growth

Men who are given opportunities in graduate teaching are usually intelligent; their defects are commonly in courage when they dare not disagree, in persistence, in imagination, and sometimes in intellectual honesty. For the young man there are well-known outward stimulants to growth—study, publication, travel, practical experience, committee work, active work in professional societies; but all of these can be overdone and no one of them nor any combination will alone add greatly to his intellectual stature. Only those who have the will toward intellectual growth achieve it. The absorption of other men's ideas readily becomes a vice; too much publication is as bad as too little; "a fool who learns to roam is no wiser than one who stays at home"; experience does good service but is often a dangerous master; excessive committee work may hopelessly dissipate valuable energy; and professional societies turn out many useless reports. But, nevertheless, in each of these devices lies the stimulation that accounts for the development of many of our great teachers of graduate students.

How, then, may an institution help to develop its graduate faculty? By sympathetic understanding of their problems, support of their objectives, and appreciation of their accomplishments—all with full realization that in the graduate field the institution cannot possibly be more distinguished than is its graduate faculty.

Those truly great should be cherished, those who would be great should be encouraged, and if and when they grow, they should be rewarded. But gilded dust must be distinguished from gilt o'erdusted; ability to make the distinction with assurance is rare, but it is essential to those who would help to form a graduate faculty.

(5) Admission Requirements for Master's and Doctor's Degrees

The value of a master's or doctor's degree is colored by the reputation and success of the men who have previously received it. It is somewhat like the hallmark on sterling silver and should be awarded only to those who have clearly proved their worth. Admission to candidacy for a degree is not a right but is a privilege which may be withheld or granted at the discretion of the school in which the student desires to study.

Standards of Admission

Colleges of engineering should not accept a student for graduate study whose undergraduate record has not been better than average. In fact, only students who rank in the upper quarter of the graduating class are likely to become strong candidates for an advanced degree. Special attention should be given to the adequacy of and standing in courses in mathematics and the physical sciences and English because they form the foundation for all graduate study in technical fields.

It is often wise to accept an applicant as an unclassified graduate student and admit him as a candidate for a degree only after the successful completion of his work in the first semester. His program may then be outlined with greater fairness to the student and to the standards of the school. The evaluation of graduate credits transferred from other schools may also be wisely postponed for one semester.

An acceptable student should not only have shown ability but also honesty, industry, initiative, and intellectual curiosity. The latter qualifications may be evaluated only imperfectly. Letters from the dean and from one or two professors who have known the man as an undergraduate will help to determine the student's qualifications. If the student has a background of industrial work, letters from employers will be helpful.

Entrance Examinations

Entrance examinations before admission to study for the master's degree involve many difficulties. They cannot be given conveniently before the student arrives to commence his graduate work, and if given at the beginning of his term of residence, they are difficult to evaluate because of the variations in undergraduate training and also the brightness or rustiness of the candidate's preparation. The Graduate Record Examination when fully developed may give a good picture of the candidate's general breadth of background. Of course, it makes no attempt to evaluate his specialized technical qualifications. Entrance examinations may, therefore, be considered as complementary to other factors in evaluating the student's standing. They are less significant than entrance examinations to undergraduate study because much more evidence concerning the qualifications of postgraduate students is readily available in the record of the undergraduate studies.

Preliminary Examinations for the Doctorate

Students should not be accepted as candidates for the doctorate until they have shown their proficiency by a year of graduate study which includes work in mathematics (see section 10) and the theoretical phases of some branch of engineering. Admission to study for the doctorate should be granted only to those who excel in meeting the general requirements outlined for the master's degree. Preliminary examinations for the doctorate are essential. Some deficiencies in preparation may be overlooked in an applicant for the master's degree, but they should not be permitted in one who is applying for the highest academic honor.

The preliminary examination should establish the student's understanding of the important theoretical phases of the undergraduate program as well as the general subject matter of completed graduate study and should require the use of mathematics and of the physical sciences. This examination is discussed more fully in Section 11.

(6) Awarding and Earning Advanced Degrees in Engineering

Educational programs leading to graduate degrees are so varied in scope and in objectives that universal requirements for the master's and doctor's degrees in engineering cannot be narrowly specified. It seems generally agreed that admission to graduate study will usually depend upon completion of the work for the bachelor's

degree in the same or in a supporting field, but capacity to advance in graduate study is clearly the only essential criterion. The formality of completing undergraduate courses that are not necessarily prerequisite to the graduate studies is unwarranted if the student holds an accredited degree.

Residence Requirements

A required residence period of one academic year at the institution granting any advanced degree is apparently universal and three years of postgraduate work at institutions with high standards of graduate study is common for the doctorate. These formal requirements seem reasonable and proper although faculties have the privilege of setting their own rules and of treating exceptional students in an individual manner.

Bilateral Character of Formal Requirements

There is no doubt that strong engineering colleges can and will maintain and elevate the stature of their master's and doctor's degrees. Graduate schools will continue to select their degree-candidates from among men and women of distinctive promise and scholarly performance. Meanwhile, the *student's* requirements for postgraduate educational opportunities must not be overlooked. Just as the school should have reasonable assurance that the student is a good scholarly risk, the student should have a like assurance that the school can offer him the graduate program he desires. Thus, the formal requirements for graduate degrees should be based on a bilateral analysis of the obligations of student and school, and the faculty should freely recommend other institutions that might better serve the student's individual needs.

What essentially constitutes a graduate program? How does it operate? Who keeps it moving? . . . If questions like these can be answered, many of the formal requirements for advanced degrees will be outlined implicitly. Formal documentation of these requirements in administrative regulations, which can impel the effective operation of a graduate program, should be indigenous to each graduate school.

Devices and Methods of Graduate Study

Graduate work in operation is ideally a process of self-development of the student. Necessity for group instruction and formal class work at the graduate level bears an inverse relationship to the scholarly maturity of the student or to the catalytic capacity of the teacher. This does not imply that lectures and formal instruction are inherently bad. Indeed, they may be desirable and economical in smoothing the transition from a heterogeneous background of undergraduate instruction to forthright progress of the individual graduate student at the postgraduate level. Among incentives and spurs to student self-development, it may be emphasized that: (*a*) *Teachers* should stimulate students to self-action and then guide and question rather than lead and inform. This assumes that the purpose is to develop the graduate student rather than to carry out a program of institutional research. The kind of leadership which develops individual research capacity may be quite different from the kind of leadership necessary to manage an institutional team in research. (*b*) *Seminars* in which the students themselves sup-

ply the ideas and learn—under the guidance of the staff leader—to test their own thinking processes may be far superior to formal lectures or laboratory manipulations. (*c*) *Laboratories*—analytic and bibliographic as well as experimental—provide the basis for sound discussion and study of problems within the student's advancing horizon. (*d*) *Formal reports*—written and oral—help to develop accuracy of statement and new or different points of view. Short articles or discussions of current papers which find their way into publication are powerful stimulants to developing the student's interest in the stream of professional progress. (*e*) *Systematic habits* of noting, assembling, tabulating, and analyzing pertinent matter from day to day should be developed early in the student's program.

Applying and Relaxing Formal Requirements

For purposes of administration a graduate school may find it necessary to formalize its standards for master's and doctor's degrees by surrounding the fields of scholarly pursuits and human development with requirements concerning such matters as admission to the graduate school; major and minor fields; distribution of time between courses; credits; residence; continuous or overall period of study; admission to candidacy; language certification, proficiency, or purposeful use; qualifying examinations; research and thesis; final examinations; publications. However, at intervals the real thoroughbreds should be permitted and encouraged to hurdle these administrative fences and to grow and exercise in their professional fields as individuals and potential leaders.

For the gifted and earnest graduate student and the truly great graduate teacher, the metaphor is inept. For them teamwork, adequate laboratory and library facilities, mutual confidence and good will, and a minimum of formalism will develop distinguished masters and doctors—but their numbers will probably be small. The college will need its formal requirements for its average students, but college administrators should not forget that the graduate field is the province of the superior mind.

(7) Distribution of Emphasis Among Major, Minor, and Research

Definition of Major.—For the purposes of this discussion, the term "advanced degree" means either the master's or the doctor's degree in engineering with or without designation of field of specialization. The term "major" refers to a field of scientific or engineering specialization for an advanced degree. It comprises all subjects which contribute toward attainment of competence in that field.

The subjects which make up the major may be offered all in one department or may be distributed among several departments. Nothing appears to be gained by maintaining a restriction of the term "major" to offerings of a single department. Departmentalization of a faculty is a mechanism of administration and does not indicate the existence of boundaries between the various centers of scientific emphasis which give the names to departments. Subjects contributory to a major, offered in departments other than that in which a student is enrolled, may require articulation into

the major program if the student is to receive the best education. Interdepartmental service of this sort is advantageous to all concerned.

The attainment of professional competence is advanced also by skill in research, and the development of this type of skill is appropriately a part of the major field. Research is investigation by orderly and scientific method for the establishment of truth by discovery, application, or confirmation of tentative findings.

It is fully realized that the definition of "major" offered in this report cannot coincide with all of the various definitions of major which are a matter of current record or of unwritten understanding. This definition is offered as having a sound basis in logic and a useful distinction from that of "minor" presented below.

Definition of Minor

The term "minor" in respect to a program leading to an advanced degree appears to be justified only if it designates something that is essentially different from a major requirement. Unless there be in the approved type of graduate program such an element of difference worthy of perpetuation, it would be much better to drop both the terms "major" and "minor." The occasional use of these terms to differentiate among courses contributory to the same profession or field, including subjects cognate with those offered in a socalled "major" department but offered in another department, appears to serve no useful end. Hence, since all work for the master's degree usually contributes toward one professional objective, the term "minor" can be omitted from a discussion of this degree.

The Minor in the Doctorate

For the doctorate there is real meaning to the term minor which designates a unified study of a separate field of science or applied science. A minor study in any field of the natural or social sciences should be permitted when it is clearly established that such study will contribute directly to the proposed research project. A common unit comprising a minor study would consist of integrated courses representing approximately the full-time work of one semester out of the six required for the doctorate. An obviously useful minor study for the doctorate in any field of engineering or science would be mathematics. Some schools assume that one minor study will be in mathematics for nearly all candidates for the doctorate in engineering. A second minor study, closely related to the major study, may be chosen, but, according to the definition given here, this work may more appropriately be classed as a part of the major. As an example, the chemical engineer may take a minor in physical chemistry or the work in physical chemistry may properly be accepted as a part of the chemical engineering major. The same close relationship exists between electrical engineering and certain courses in physics or between civil or mechanical engineering and mechanics. Therefore, it is strongly recommended that the choice of courses comprising the major study be made liberally and without reference to departmental lines but that one minor be required in a field clearly separated but contributing to the strength of the major study or the research.

Relative Emphasis on Research

An appropriate proportion of time of the major to be devoted to research appears to be greater in programs leading toward a doctorate than in those aimed at a master's degree. For the master's degree it may properly be greater in programs of students preparing for research or development or other creative activities, on the one hand, than in those pointed toward the less scientific phases of engineering on the other.

The emphasis upon research in a master's program, as recommended in another section of this report (Section 8), should be directed toward training in techniques of research or scientific design and will not include a requirement of demonstrated ability in original research leading to a contribution to knowledge. The master's degree need not be a "little doctorate."

It is recommended that not less than one-third the major time allotment in a doctorate program (including the time for the master's degree) be devoted to research and that not less than one-fifth the major time in a master's program be devoted to the investigation or thesis study. A greater proportion of time spent on research is to be encouraged for any student who shows early acceptance of complete responsibility for the use of his time when it is undirected. This capacity is not found fully developed in all graduate students by any means.

Discussion

The suggestions made herein for distribution of time among major, minor, and research aspects of programs leading to advanced degrees cannot be rigidly applicable in all cases, but should serve merely as range marks in plotting a course of study. The distribution of emphasis appropriate today may require alteration as undergraduate engineering curricula evolve as recommended by committees of our Society, particularly in the development of ingenuity and research capacity. There is every reason to encourage experimentation with such methods of introducing exceptional undergraduate students gradually to the experiences of graduate study.

(8) Usefulness and Proper Content of the Graduate Thesis

The preparation, execution, and defense of a thesis is an extremely useful part of professional training.

It is normally required that the master's thesis demonstrate the ability to analyze a problem clearly and either to carry on a research assignment with reasonable guidance by the thesis adviser or to develop a design incorporating novel features. In most cases, the master's thesis in engineering is the first acquaintance of the student with independent design or research work and it is often used for the training in methods and procedures relating to research.

The requirement for the doctor's dissertation is invariably independent research culminating in an original contribution to engineering. The doctor's degree is considered primarily as a research degree in engineering and in many instances the master's degree is made a prerequisite in order to obtain reliable preliminary judgment of a student's research ability.

The term "thesis" is used to denote, variously,

(*a*) A proposition to be investigated or tested.

(*b*) The actual investigational effort of research or testing.

(*c*) A written dissertation on an investigation submitted in partial fulfillment of requirements for an academic degree.

The development of a thesis offers a most valuable and practical opportunity to the fledgling scientist or engineer to try out his own professional wings, and to demonstrate to himself and to his fellows that he is able to make progress on his own initiative and by his own efforts.

Selection of a Thesis Subject

Ideally, the thesis should be an orderly, planned attempt to satisfy constructive curiosity in discovery or in substantiation of truth. It will best be chosen in respect to available facilities, instructional personnel, and time for its prosecution. In the process of selection and restriction of the proposition to be laid down as a thesis, services of the experienced teacher are likely to be especially valuable.

The neophyte in research, if left to his own devices, often selects for investigation a topic which involves considerations too elaborate, too difficult, or too comprehensive to be handled satisfactorily in the time at his disposal. This optimism of youth is a distinct asset to any investigator and should be preserved as long as possible by persuading the young research worker to be moderate in his objectives. If he is able again and again to achieve success, he will progress from the smaller to the greater with a minimum of discouragement in the early stages.

In selection of thesis problems, it is wise to restrict the choice to those in which the general technique for attack is already a part of the student's equipment. As he delves deeper and deeper, the investigator may expect confidently to meet situations which will be novel to his experience, in the attack upon which there will be opportunity for full play of his powers of origination and of his ability to master new techniques.

Formulation and Attack upon the Problem

It is useful in planning a thesis to outline its principal subdivisions and to forecast in so far as possible whether the problem as analyzed is likely to be solved in the time allotted for it. Such an analysis by the student may well be the substance of a first report on a thesis to the faculty supervisor of his work. What should a preliminary report include? The proposal presumably has a definite objective. It is helpful to define that objective reasonably and explicitly. What are the reasons why the problem has interest? Some of these reasons may be general, some personal; they may be based on historic traditions or upon some new pronouncement which needs verification, or because of long standing lack of information upon some special aspect of a larger problem. These matters briefly presented in a preliminary report justify the selection of the topic chosen.

Having formulated the question and having justified its selection, there next comes the planning of an attack upon the problem. In efficient planning, the larger objectives are subdivided into a series of lesser ones. These are attacked one by one: a given experiment is set up—if the result is positive, then the tentative conclusion is clarified, but if the result is negative, then one will try a new attack. The number of repetitions of a given experiment that is needed for the correct tentative con-

clusions is a matter controlled by the theory of precision of measurements, presumably a part of the training of every scientific research worker. Finally an estimate is made of the time needed to complete the work outlined plus that needed for unpredictable additions and variations, and compared with the hours available.

Validity of Results

As a result of experimentation, if careful and detailed records have been kept, there are available the data upon which conclusions can be established. Such conclusions will depend upon the soundness of deductive reasoning used in their derivations and upon the validity of the data upon which they are based. A consideration of methods of obtaining data is therefore in order, early in the thesis study, perhaps even in its preliminary stages of planning.

Among the factors which influence the validity of experimental data are the following:

(*a*) Reliability of procedures selected; experimental error inherent in methods or materials; number of repetitions needed of a given test; method of analysis of results.

(*b*) Types of apparatus and design of new apparatus; its calibration and methods of use.

(*c*) Effects of variations in methods, control over conditions, use of confirmatory or check procedures.

Content of the Thesis

An outline of thesis content, then, might include:

I. Introduction
   (*a*) Statement of the thesis problem, with desired objective clearly defined, and an explanation of why it was chosen for investigation.
   (*b*) A summary of the history of the case including a digest of publications thereon. (The actual bibliography is more conveniently attached as an appendix.)

II. Text Matter or Body
   (*a*) An analytical plan of approach to the solution of the problem and the initial experimental steps to be taken.
   (*b*) Experimentation according to orderly plan with accurate and detailed recording of conditions and results.

III. Conclusions and Summary
   (*a*) Evaluation of findings and formulation of conclusions that are justified by the data.
   (*b*) A digest of the report as a whole and suggestions as to further work, in the light of the work reported.

The final form of the written thesis should be such that anyone versed in the art which comprises its subject matter, anywhere, at any time, by perusing it can ascertain: (*a*) the object of the work, (*b*) why it was undertaken, (*c*) what others have thought about the subject, (*d*) why previous views or data were unsatisfactory, (*e*) what the writer did to improve the data, (*f*) what details of technique were employed, so presented that exact repetition is possible, (*g*) what conclusions were drawn and why, (*h*) who did the piece of work, when, and where.

Objectives and By-Products of Thesis Research

The broad objective of research is the establishment of truth either by discovery or by confirmation. Negative findings which narrow the field of possibilities of an unknown, have the effect of convergence upon the truth, and convincing proof that certain things are not true should be as acceptable—though not as soul satisfying—as positive findings. By experience, the investigator comes to tolerate the miss with the hit provided each is the result of a sound attempt. This attitude of mind of the searcher for truth is a valuable possession for a professional man. Its acquisition may be considered as one of the valuable by-products of research.

Another good that comes incidentally from thesis work is the training in explanation and self-expression that ensues if thesis readers are sufficiently exacting in requiring that dissertations be understandable, logical, and convincing, expressed in clear and correct language. A scientific dissertation is not primarily a piece of literature; it, of course, must not be fiction; it rarely is likely to be poetic; but *it can and should be an example of convincing exposition.*

Objectives of the Master's Thesis

It is only at the doctorate level that there is justification for the requirement that a thesis shall comprise an original contribution to knowledge as evidence of expertness acquired. In respect to the thesis for a master's degree, the time conventionally assigned is limited and the student is usually inexperienced in research. It should be clear, therefore, that the objectives of the master's thesis are not necessarily the same as those of the doctorate.

Among the suggestions which seem reasonable and acceptable covering the thesis requirement for the master's degree in an engineering field are the following: (*a*) A small experimental or theoretical research, of the same type as that for a doctorate. (*b*) An exercise to develop research ability rather than a demonstration of research performance. (*c*) An exercise in solving a practical engineering problem involving novel features, which may or may not comprise design, and without required experiment. (*d*) A graduated series of projects beginning with a problem for solution by use of the usual facilities available to an engineer, with considerable initial guidance but culminating in independent effort with little or no guidance. (*e*) A report based on the literature concerning a selected topic, with interpretations thereof.

Professional Function of the Master's Thesis

Whatever form or type of thesis is prescribed, there is a certain sequence of attainments in the education of an engineer before he is entitled to be considered as professionally competent in his own right. At some stage he must learn to do homework; this is an early test of power of independent accomplishment. At some stage he must learn to meet examinations. When under employment he must be able to secure and furnish reliable answers to questions put to him by his superiors, and when in charge of design, construction, or operation of engineering facilities he must be able to meet the problems posed by circumstances.

College training can aid him in many of these steps toward professional per-

formance, and the thesis offers an opportunity for growth from student status to that of professional performance.

If, then, one accepts the principle that in the curriculum leading to a master's degree in engineering, the master's thesis is first considered as a contribution to the training of the candidate rather than a contribution to knowledge, immediately the educator finds himself on firm ground. The common absence of conviction that master's theses are worth evaluating as contributions to knowledge ceases to have importance. Where a master's thesis does contribute something new, that is a welcome fact of interest.

By acceptance of this rational objective for theses of the master's grade, one finds that judgment of the appropriateness of alternatives has a logical relationship to the other training of the student. If his program exclusive of thesis has shown an emphasis upon investigational or experimental classwork, then obviously a thesis topic in design or problem solution will tend to round out preparation. On the other hand, if the student's program or present capacity shows weakness in investigational techniques, an experimental thesis would seem to be more appropriate. It is recognized, of course, that some students destined to be extreme specialists can with profit devote all studies toward a more narrow objective.

(9) Language Requirements for Advanced Degrees in Engineering

In 1934 the Office of Education of the United States Department of the Interior undertook a survey of graduate work in engineering in coöperation with the Committee on Graduate Study of S.P.E.E. Included in the survey were data from 83 schools that granted master's degrees in engineering and 34 schools that also granted doctor's degrees in engineering. The report of that survey, published in 1936, presents the following interpretation by the committee with respect to—

"Language requirements.—In work for the doctorate, a reading knowledge of two modern foreign languages is required almost universally. Apparently the traditional requirements of work in pure science, the classics, and philosophy have been adopted in engineering without much consideration of their relevancy. It is of some significance, perhaps, that in programs of work for the master's degree, which have developed in closer relationship to undergraduate work in engineering and often under the direct guidance and control of the engineering faculty, language requirements are usually not imposed. Further study might well be given to this whole matter." *

Foreign Language Study by Undergraduates

Assuming that graduate students in engineering should first be engineering graduates, it is appropriate to consider the pattern of engineering education at the undergraduate level. The Committee on Aims and Scope of Engineering Curricula in 1940 recommended a pattern made up of sequences of subject matter in two stems: scientific-technological and humanistic-social. In these two stems, as recommended by that committee, a foreign language proficiency is not implied.

* W. C. John and H. P. Hammond, "Graduate Work in Engineering in Universities and Colleges in the United States." Bulletin 1936, No. 8, pp. 85–86. U. S. Department of the Interior, Office of Education.

Again in a report of 1944, the Committee on Engineering Education After the War adopted the same point of view about undergraduate education with relation to the study of a foreign language.

It is unlikely that the engineering graduate will have even a rudimentary knowledge of any foreign language as a consequence of his undergraduate education whether he be trained according to the usual pattern of the engineering undergraduate, according to a pattern aimed toward operation and management in industry, or according to a pattern aimed for higher levels of scientific study. Except for some brief experience in the high school, the graduate student in engineering is most likely to come to grips with a foreign language only *after* he has earned his master's degree. Only in undergraduate chemical engineering is the study of German often required.

Usual Language Requirements for the Doctorate

Recognizing further that candidates for the doctor's degree in engineering have usually completed the requirements for the master's degree, the pattern of engineering education at the early graduate level also has a bearing on language requirements which may be appropriate for the doctor's degree. With the master's work planned as a terminal program for which a foreign language is not required, the engineering schools are requiring two foreign languages to be mastered by the student in the single year before he enters his last year of residence for the doctorate. This is the effect of the almost universal requirement of two modern foreign languages—usually French and German—selected with little consideration of their relationship to the student's major problem or to his future work. The result, of course, is that one must be satisfied with a rather superficial ability to translate material in these languages.

Several questions may be asked with regard to the foreign language requirements for the doctorate in engineering:

If one or more foreign languages are necessary as a tool of research, should not foreign language occupy in the student's graduate program a place comparable to English in the undergraduate program?

Is the graduate student required or encouraged to use his foreign language (or languages) as a tool, or is the language hurdle merely a disciplinary device?

What proficiency is expected of the student in foreign languages and to what end?

Are the methods of language instruction available to graduate students pitched at a mature level and aimed to develop systematic language habits in keeping with other disciplines of graduate instruction?

Should not some of the best talent of language teachers be directed toward helping the best engineering talent at the graduate level *make use of* a foreign language? How much more stimulating this could be than allowing the graduate student to shift for himself in acquiring "a reading knowledge" of French and German!

Alternative Single Foreign Language Requirement

Instead of accepting a superficial "reading knowledge" of two foreign languages, it is recommended that one foreign language used purposefully by the student in his major field of study be considered equally acceptable. If the foreign language is to be a tool, the

graduate student must be required to demonstrate in his program of study that he can and does use that foreign language effectively and extensively in relation to his project or thesis. It is self-evident that careful control must be exercised over the single language requirement or it will drift downward toward the present superficial reading knowledge which has been criticized in the two-language requirement.

What language? That would reasonably depend on the student's major field. Commonly it would be French or German but, with equal purpose, it could be Italian or Russian or some other language chosen because of its literature in the major field of study.

Thus, at his qualifying examination the doctoral candidate should demonstrate that he is able to use one foreign language effectively and at the final examination there should be evidence presented of its use—and not merely the common certificate of "reading knowledge" of French and German. Whether this alternative is more rigorous or lenient than current requirements and whether it will be found difficult to administer may be debatable. There can be little doubt that once one foreign language is learned and used extensively in relation to one's field of interest another can be learned with relative ease.

(10) Mathematics as a Part of Graduate Study in Engineering

Graduate study in engineering emphasizes the mathematical or scientific approach to the solution of technical problems. Analytical studies are far more important in graduate work than informational courses since the art of engineering is to be learned mainly in practice rather than in graduate classes. Mathematics is the primary tool of engineering but undergraduate curricula seldom include required courses in mathematics beyond the integral calculus.

An ability to use mathematics beyond undergraduate courses in differential and integral calculus is essential for engineering graduate study. A knowledge of differential equations has a particular value in mechanics, the functions of a complex variable are much used in electrical engineering, while an understanding of statistics as applied to the interpretation of engineering data adds to the effectiveness of the investigator. In addition, the rigorous logic of the mathematical approach (premises clearly stated; conditions of sufficiency exactly defined) is excellent training for research workers in all fields.

Mathematics Required for the Master's and Doctor's Degrees

It is recommended, therefore, that the master's program in engineering include one or more courses in mathematics beyond integral calculus and that the doctorate in engineering should commonly be strengthened by requiring the student to complete the equivalent of a minor study (defined in section 7) in mathematics. In some institutions these courses can be taken within the framework of the college of engineering. To meet the mathematics requirement, such courses in advanced mathematics should be taught by competent mathematicians who may also be engineers. If the courses are primarily courses in mechanics, electricity, or thermodynamics, they may be of the greatest value and still not be sufficiently rigorous mathematically to meet the objective discussed. Evi-

dently, courses in engineering analysis should be devoted to the problem of expressing physical conditions through mathematical equations. The solution of the equations is taught in mathematics courses. Either is incomplete without the other.

(11) The Examination of Candidates for Advanced Degrees

Examinations of a comprehensive type play an important role in graduate study. They can be and are used effectively at several different points in the program: (*a*) at entrance, to ascertain whether the student is qualified for graduate work, (*b*) at the end of the master's degree work to determine whether he merits a degree, (*c*) at the beginning of the doctoral research investigation to determine the candidate's qualification for such work, and (*d*) at or near the end of the doctoral program as a basis for awarding the degree. This final examination is commonly restricted to the doctoral research and related subjects. In addition, there are examinations to test proficiency in languages and examinations in course, but these are not considered here.

Entrance Examinations

The first class of examinations, those for entrance, has been discussed in section 5. The examinations appear to be rarely used, possibly because of the difficulty of administering them to candidates before they are admitted, and also because there are other useful criteria of a prospective postgraduate student's qualifications. Preliminary examination for candidacy for the doctorate will be discussed below.

Degree Examinations

Comprehensive examinations of the other three classes are common. More or less emphasis is placed on them depending upon the institutional policy. It seems evident, however, that they should be regarded as highly important, in fact, important to just that extent to which graduate work departs from formal study in course and approaches the development of the individual by his working on his own initiative in reading, in research, and in seminars. When the material that the student is expected to master is organized for him in formal courses and tested therein, the ground covered is known (although not always how well it is retained), but when the work is done more nearly on the basis of individual initiative, some comprehensive test is necessary to insure that essential subject matter has not been overlooked or slighted.

Another aspect of the comprehensive examination which is perhaps even more important than the testing of the student is the function of directing and holding the attention of both students and faculty on the goal of the program, and clarifying the objectives of graduate study for them. A statement in words of the objectives of the program often fails to impart to the reader a clear, accurate picture, and indeed widely different programs may be described in the same way. But the problems of a good comprehensive examination give both students and faculty a concrete picture of what the student is expected to know and to be able to do. At best it is difficult to express educational objectives in quantitative terms, but some of the difficulty may be avoided by describing them in terms of examination questions.

Responsibility for Results of the Examination Procedure

Since the comprehensive examination expresses the objectives of the graduate program and is the means of testing whether they have been achieved by the individual, the preparation of the examination should be the responsibility of the departmental or divisional graduate faculty. In a large group the detailed work of examining may be delegated to a committee, obviously including members of other departments, but the responsibility of the group which determines the student's program of graduate study cannot be avoided. The underlying point of view should reach beyond the individual courses of the program to its ultimate purpose, and the examination should be framed not as a collection of course examination questions but in terms of objectives of the student's overall program. Thus there is a system of checks which keeps the individual staff members pulling together in a common direction. The examination in terms of general objectives not only helps unify the program, it gives point to the concept that the parts of the program must be integrated.

Written and Oral Examinations

The most effective examination is probably one consisting of a written followed by an oral part. The relatively subjective oral type permits the examiner to probe more thoroughly and determine the limits of the student's understanding, yet does not lend itself as well as the more objective written type to testing the candidate's ability to perform successfully an involved analysis or to make a complete design. The oral examination, often requiring skillful handling to avoid stage fright, is time consuming; the written examination conserves at least the time of the examiners.

Doctoral Examinations

For the doctorate it seems desirable to have a preliminary examination consisting of a written followed by an oral part. The purpose of these examinations is to sample the whole of the candidate's background and to try him in one or two relatively involved situations. It should require the use of mathematics and, for most candidates, physics of sufficient difficulty to test one's knowledge in these fields. The purpose of the oral examination should be to probe further any weaknesses that appeared in the written examination, and to ascertain the student's resourcefulness and his philosophy. If he fails, the oral examination should make clear to him the reason for failure. In the case of the final examination, preceding the doctorate, the oral examination gives the candidate an opportunity to defend his thesis work, and this is often its chief purpose.

It is recommended that greater emphasis be placed on comprehensive examinations of the combined written and oral kind, not only as a yardstick to measure the degree of the student's attainment, but also as a rather tangible expression of the objectives of graduate study and as a means of directing them to the attention of students and faculty.

(12) Acceptance of Undergraduate Course Work for Graduate Credit

A consideration of this subject involves some definition of the purpose of graduate study. It may be sufficient to say that graduate study should com-

bine an intensive training in a limited field with some studies intended to give a broader base for a professional career. Graduate courses in the field of specialization should be rigorous and should not shrink from using advanced mathematics. The student should be required to develop fundamental equations and not use empirical formulas from handbooks.

If undergraduate courses meet these standards, they may well be accepted for graduate credit. However, not many undergraduate courses, even those offered to seniors, reach the high level of graduate courses. It seems clear that institutions should limit consideration for graduate credit to junior and senior courses. The presence of a majority of undergraduates obviously limits the level attainable and, naturally, any course in which a majority of the students are unselected undergraduates must be handled as an undergraduate course.

Study in Collateral Fields

A student may take some undergraduate courses in fields collateral to that of his primary interest but only a minor part of his program can be made up of such courses (see section 7). It will be almost necessary for him to elect some courses for undergraduates in collateral fields because he will not have the training to compete with graduate students who are pursuing the subject as their primary study. Nevertheless, it is recommended that no more than 25 per cent of the master's program be permitted in approved undergraduate courses. To raise the educational value of this part of the graduate program, it is recommended that (*a*) additional assignments be required of graduate students in undergraduate classes, or (*b*) a reduction of about one-third be applied to the course credit, or (*c*) a system be adopted of designating borderline courses for attendance only by graduate students and selected undergraduates.

Transfer of Excess Undergraduate Credit

Most graduates have a few undergraduate credits in excess of the minimum requirement for the bachelor's degree. Acceptance of such credits toward an advanced degree when they were not originally taken with approval for graduate credit merely acts as a general reduction of the minimum standard for an advanced degree. It is therefore recommended that undergraduate course credit be accepted only for courses taken after graduation as an approved part of the master's program.

Under no circumstance should graduate credit be granted for an undergraduate course unless the student has secured a superior grade in that course.

Undergraduate Courses in the Doctor's Program

Very little additional undergraduate work should be elected by a student who has advanced beyond his first year of graduate study. Less than twenty-five per cent of the approved course work for the doctorate should be permitted in the undergraduate field and such courses should be accepted only if they form part of an approved educational objective.

(13) Study in Economics, Political Science, or Administration

It is recognized that study in economics and administration is a desirable but not a necessary part of the training for all engineers. Some

schools maintain joint programs in engineering and administration leading to either a bachelor's or a master's degree. In other cases students may wish to prepare for public service by the study of political science or desire the breadth of understanding coming from further study of other fields. It is assumed in this discussion that the student is a candidate for a master's degree with a major in some field of engineering and that only a minor part of his time is to be devoted to the study of economics, political science or administration.

Students with a major in engineering cannot usually enter courses which are rated as of graduate caliber for students specializing in these other fields. The query is whether undergraduate courses in economics or similar subjects should be accepted for graduate credit, and it is recommended that such course credit may be acceptable if it forms part of an approved educational objective and meets the other specifications of section 12. For the doctorate the use of liberal studies to fulfill the requirement of a minor has been discussed in section 7.

Work for men must be done with men; human relations between engineer and client can make or mar success. The key to successful human relations seems to be community of interests and a mutuality of understanding. It is an obligation of the educator to equip his students with more than the technical intellectual resources of a profession; they should be led toward an understanding of the social and economic environment which to so large a degree has been shaped by science and technology. Since there is so little opportunity for social studies in graduate work in engineering, the engineering graduate teacher carries a heavy responsibility for sensitizing his students to the importance of their future relations with people by example and by suggestion for liberal readings. The recipients of advanced degrees in engineering will be much more influential if they are able to take their places in the world of men not only as engineers but as effective citizens.

(14) Evening Graduate Study

The never static processes of education represent an effort to establish, for any given period and circumstances, an equilibrium between the facilities of our educational system and the needs and desires of the public. One of the interesting characteristics of education is its flexibility and adaptability to changing conditions. In the present discussion, we are dealing with advanced study by a select group of students, namely, those who are employed during the day and therefore, cannot give full time to advanced study toward a higher degree. By the nature of circumstances, such courses are offered in the late afternoon or evening and represent a coördination of theory and practice, since a great majority of the students are employed in the fields of their major studies.

Development of Evening Graduate Study

Although not a new development, the formal organization of evening graduate study is relatively new and is rapidly becoming one of the significant features of education in the field of engineering. It is therefore appropriate to review briefly the circumstances which gave rise to this development. Traditionally, graduate study has been undertaken in day courses, either by full-time students or by graduate assistants, teaching fellows, research fel-

lows, or on some other subsidized level. Two disadvantages of this traditional system are recognized: (*a*) the entrance upon professional practice is delayed against the natural desires of the student. (*b*) many students of graduate caliber are unable to undertake graduate study for financial reasons.

Shortly after World War I, many institutions, especially those in large industrial centers, began to receive inquiries from graduate engineers engaged in local industries, regarding graduate courses to be offered in the evening. In due time, accordingly, graduate courses which were originally offered during the day were repeated in the evening. In every institution where this was done, a substantial increase in the number of graduate students resulted. The success of earlier efforts has encouraged many institutions, especially those in large cities, to offer graduate courses in the evening.

Categories of Evening Students

Because of the fluctuating character of wartime registration, it has for several years been impossible to compile representative figures regarding the number of evening graduate students in the United States. It is estimated that some 2,000 students fall into this category. These students may be classified into two groups: (*a*) candidates for higher degrees, (*b*) registrants for special courses. No breakdown of the two groups is available.

The full-time graduate student normally completes the requirements for the master's degree in one year and the doctorate in three years after the bachelor's degree. Where a candidate is performing simultaneous services as assistant, research fellow, and the like, the time required is extended. Graduate students who are studying in the evening while employed during the day take longer because of part-time study and because of unforeseen interference caused by obligations to their business connections. Hence, candidates for the master's degree take from two and one-half to three years of evening study beyond the bachelor's degree.

Specialized Postgraduate Courses and Auditors

As indicated, all evening graduate students are not necessarily candidates for a higher degree. One of the functions of a graduate university is to provide comprehensive and coördinated education in a particular field leading to an appropriate advanced degree. Evening graduate schools have a second objective to provide advanced courses of specialized interest for those already possessing an advanced degree or for other qualified individuals who wish to extend their knowledge of a particular field for direct use in their industrial work. This explains the presence of a limited number of nondegree candidates in evening graduate courses. It should be pointed out here that care must be exercised in determining the admission of members of this group to ascertain that they have the proper background to take the course advantageously and to perform all assignments. *Auditors* reduce the standards of the graduate course and should be permitted only in exceptional cases.

Characteristics of Evening Graduate Students

Practically all evening graduate students are employed during the day in an industrial field directly related to the

major field of concentration of graduate study. Many evening students are in positions of responsibility. Generally speaking, evening graduate students are older than the usual day students, and bring to their graduate studies a contemporary knowledge of the subject resulting from their industrial contacts. Lastly, practically all evening graduate students are paying full tuition for graduate study, which introduces a factor of peculiar earnestness. Study in the evening after a normal working day is an added burden, but the extra effort is stimulated by the combination of factors indicated above.

Evening Faculty

Large corporations, located within convenient commuting distance of a graduate engineering school, will often have on their staffs outstanding scientists who are specialists in certain fields of knowledge. As the graduate courses are offered in the evening, these specialists are normally available as teachers. These special lecturers, because of daily contact with the practice of their specialty, are able to present the latest practices which have not reached the literature. Industry's scientists are highly stimulating as teachers of such courses as gas turbines, design of transformers, and other specialties. It is the common experience that day school teachers are more effective in handling the basic courses such as advanced mechanics and thermodynamics. They should be encouraged to teach such evening courses.

Research for Evening Students

Whereas it has been the general practice to assign the student to an appropriate member of the faculty to select a topic for research under close direction, the coöperative nature of evening graduate study through the student's association with industry gives rise to a different possibility for handling research. The student may have an interest in a particular field of research which is often of direct interest to his company. This interest of the company may develop to the point that it may subsidize the research in whole or in part.

Where the required equipment is not available at the university, the company may permit the use of its own equipment. This arrangement makes possible investigations which ordinarily could not be carried out. The arrangement for the credit value of such research will be discussed later in section 16. Lastly, in order to complete the research as quickly as possible (particularly for the doctorate), the graduate student may be given a leave of absence and transferred temporarily to the university on a full-time basis.

(15) Coöperative Graduate Study in Engineering

Coöperative engineering education has demonstrated its usefulness in the undergraduate field as an alternative to full-time engineering education. The use of the expression "full-time" for comparison with "coöperative" is recognized to be inadequate and confusing because a considerable percentage of engineering undergraduates engage in gainful activity for their partial support while an occasional student holds a full-time job and carries a full-time educational program despite all rules to the contrary.

Significance of the Job

It is fully recognized that some positions may contribute directly to under-

graduate or graduate education, but, unfortunately, some may even make a negative contribution so that it seems necessary to give little or no consideration to the job in relation to the educational requirements. For example, a shop position develops the student's sense of practical values which has unquestioned merit, but for some students this experience may close the mind in whole or in part to the importance of theoretical or the more scientific studies. On the other hand, a coöperative position in a research laboratory might clearly contribute very directly to the graduate student's development. As long as the work of the student in industry is not under the direct control of the educational institution, it seems necessary to consider its plus values as merely an additional educational experience available to some fortunate students but not sufficiently controlled to be accepted as a substitute for course work or graduate research. The possibility of using industrial investigations to satisfy the thesis requirement is considered under the heading of Residence Value of Research on Industrially Sponsored Projects, section 16.

Problems Involved in Alternation

The alternation between work in industry and in the institution produces certain problems that must be solved if there is to be no letdown in the standards of graduate study. They are associated with the importance of continuity and the loss attendant upon a partial or complete break in the educational process. This can no doubt be minimized by reading assignments and investigations to be conducted evenings during the periods spent in industry. If the company concerned can be induced to regard its coöperative employees as students, some coördinated day-time investigations may be reported upon to maintain continuity of education.

Extension of the idea of coöperative graduate study may induce more good students to start graduate work and thus contribute to an advancement of the engineering profession.

Coöperative Graduate Education with Full Employment

An interesting variant of coöperative education on the graduate level is illustrated by the Westinghouse Electric Corporation plan. Under this plan, qualified employees of the Westinghouse Corporation are enrolled as graduate students in coöperating institutions. Specialists in the employ of the Westinghouse Corporation receive regular appointments as members of the graduate teaching staff of the coöperating institutions. Regularly enrolled graduate students, not employees of the company, may also register for such courses. Only a limited number of credits may be earned in this manner toward the degree. The coöperating institution awards the degree. The plan is in operation in Pittsburgh with the University of Pittsburgh and in New York City with the Polytechnic Institute of Brooklyn, New York University, and Stevens Institute of Technology. In Chicago and Milwaukee, Illinois Institute of Technology operates a graduate program set up to encourage students from the Allis-Chalmers Company to become candidates for the master's degree. Graduate teachers from the Institute in Chicago present evening graduate classes at the Allis-Chalmers plant in Milwaukee, Wisconsin.

It has been seen from the foregoing discussion of evening graduate study

in section 14 that it also offers the essentials of coöperative education; that is, a combination of study and employment in the same field of endeavor. The evening study plan cannot be considered of general application since it is limited to those institutions located in large industrial centers where a number of diversified industries are situated. Generally speaking, students travel from industry to the campus of the university. However, in certain cases, where several large plants are near each other and located too far from the university to be reached in time for classes, a course may be located at or near one of the plants.

(16) Residence Value of Research on Industrially Sponsored Projects

In discussing thesis work in connection with industrially sponsored projects, it is always important, and sometimes paramount, to keep in mind that the thesis is the property of the institution, must be available for publication, and, in the case of the doctorate, may even be required in published form. Any research submitted for academic credit, therefore, constitutes work to which the public has full access.

To evaluate possible academic credit for research, it might be most suitable first to summarize the customary requirements pertaining to thesis work in engineering schools.

Credit for Thesis Work

In general, the total requirements for the master's degree amount to about thirty weeks of residence, defining a semester as a continuous period of fifteen or more weeks. On the average, the credit for the master's research constitutes about one-fourth of the total requirements for the degree. Translating this into full-time residence, it would be approximately one-half semester of full-time work. (Also see section 7.)

For the doctor's degree, the normal requirement is a minimum of one year of full-time residence work on the thesis research. Accepting a three year full-time minimum residence requirement beyond the bachelor's degree, the thesis research would then consume at least one-third of the total residence work for the doctorate, beyond the bachelor's degree, as explained in section 7.

Types of Research Projects

One might best classify the various arrangements which industrial organizations make with engineering schools into (1) fundamental research projects and (2) applied or industrial research projects, and might add (3) research performed by a student in a company laboratory.

Fundamental research projects are usually sponsored by industry because prominent staff members are available in specialized fields of research wherein they have established a special reputation. Such research projects are often of long range scope, and industry receives the direct benefit of prospective employees trained in a special school of thought or practice. As the name implies, fundamental research does not carry specific definitions of the objective to be achieved, and is not certain, at the start, of complete success or even termination of the originally intended work.

Applied or industrial research projects are arranged by industry usually with specific definitions of the objectives to be attained, are of limited scope, and probably are most aptly de-

scribed as "development work." Frequently, development contracts are made with special laboratories or staff members with successful consulting engineering practice, men who are known to get "results."

Frequently, particularly in connection with evening graduate schools, men employed in research or development laboratories desire to combine research for academic credit with work assigned to them in the company laboratory.

Residence Value of Sponsored Fundamental Research

Fundamental research projects sponsored by industry are the most suitable type of sponsored research to be considered for academic credit, and for the doctorate it should, indeed, be the only sponsored type so considered. Arrangements with students in such cases should preferably be made on the basis of unrestricted "research fellowships" with a grant sufficient to cover the financial needs of the student so as to leave him ample time for a combination of study and research. Research fellowships of this type would naturally carry full residence credit as is usual on fellowships sponsored by the institution, since the same freedom for work of a fundamental nature is granted.

In the case of full-time employment as staff member or assistant on an industrially sponsored research project of a fundamental nature, it becomes more difficult to evaluate residence credit. There is more tendency to press for results through subdivision or close direction of duties and to restrict somewhat the freedom in the choice of methods of attack. It would, therefore, be advisable not to give more than half-time residence credit for research work under these conditions, which means that a minimum time of at least one semester would be required for the master's thesis investigation and a minimum of four semesters of full-time residence work would be required for the doctorate research.

Residence Value of Development Projects

Development work as described above, usually does not stress the broader aspects of research problems but rather concentrates on specific detailed solutions to problems of design or operation. Certainly, such work would not be suitable for the doctoral dissertation, but it may be acceptable in connection with the master's thesis if a definite criterion can be applied to determine whether the independent contribution of the student demonstrates his ability to use effectively the generic principles as explained in section 8. If this criterion is applied rigorously, much development work which is solved by cut-and-try procedures will be discarded as an insufficient contribution to the master's program. Also, work for which the student carries little responsibility, being employed merely as a detailed assistant, must be discarded.

It is not customary to establish fellowships in connection with development work; hence, the usual case is that of full-time employment on specific projects. Therefore, not more than half-time residence credit should be allowed, and then only when the student is working in close contact with a research director who has fully demonstrated his competency in the field of fundamental research and who desires to coöperate in making the development project a significant educational experience for the student.

And, finally, the project must be one which places no restriction on the dissemination of thesis results for public benefit.

Research and Development Work in Industrial Laboratories

In order to be at all acceptable as background for a thesis, work in industrial research or development laboratories should satisfy these requirements:

(*a*) The proper authority within the company must release the work for publication before the student starts on the thesis, or else the student must accept the risk that he may not be permitted to submit his contribution as a thesis after having finished the work.

If all these and possibly other special conditions are satisfied, then the case becomes similar to that of sponsored industrial research carried on within the institution, and residence credit towards a master's project might be allowed, but for not more than one-half time. In considering the matters of residence credit, or course credit for research, it should be self-evident that the emphasis is upon the research work itself and not upon the writing of the thesis.

Summary

Recommendations for the residence allowance of research work on sponsored research projects are summarized below.

Residence Allowance Permitted for	Master's Investigation	Doctorate Research
Unrestricted research fellowships sponsored by the educational institution or by industry under full educational supervision.	Full credit for time spent.	Full credit for time spent.
Research assistants of the college employed on industrially sponsored fundamental research.	Not more than one-half credit for time spent.	Not more than one-half credit for time spent.
Students employed on approved industrial development work under qualified educational supervision.	Not more than one-half credit for time spent.	Unacceptable.

(*b*) The thesis adviser, as a member of the college staff, must be invited to visit the place of work and to inspect facilities and equipment. He should during this visit ascertain from the supervisor the extent of independent work carried on by the student and its relation to the company program as a whole.

(*c*) The thesis research must be kept continually under the direction of a member of the educational staff so that the same values will be obtained as are inherent in resident research.

(17) Graduate Institutes Serving a Single Industry

A movement is clearly discernible toward the establishment of graduate institutes devoted to the single purpose of service to individual industries. Progressive industries so served at present by special institutes are paper, gas, and textiles, while the glass companies and others are understood to be preparing to support other industry educational-research institutions. These organizations have been established with the objective of conferring

the highest academic degree, the doctorate. They embrace the physical sciences and engineering since physics, chemistry, and their engineering applications are the primary fields for industrial development work.

Considered objectively, such graduate institutes have much to recommend them. Certainly it is proper for industry to support graduate education from which it derives great benefits. It is also proper for industry to support fundamental research which contributes much to its ultimate benefit. It is not so clear, however, that these objectives are certain to be realized through such specialized organizations as industry institutes.

Divorcement from Graduate Education

There has been a tendency for the industry institute to divorce itself from traditional graduate education and to become somewhat vocationalized. The location of an industry institute in association with an institution not engaged in scientific or engineering graduate instruction or even entirely separated from an established educational institution is to be lamented. Such an institute may also become divorced from normal graduate education if the director, the board of control, and the educational committee represent predominantly the industry point of view, unleavened by significant representation of broadly experienced graduate educators. There readily develops a strong tendency toward fixed curricula having many specialized courses not significant except to one industry and clearly of less value than more common graduate courses in developing a research scientist and engineer even for that industry.

In undergraduate education there is a clear movement toward treating exceptional students in an individual manner while graduate study in science and engineering has always been highly individualized. It cannot be justified on any other basis. Even in the training program for a particular industry, it is clear that certain graduate students can effectively major in physics, others in applied mathematics, perhaps others in chemical engineering, and still others in mechanical engineering. An attempt to channelize doctorate candidates so that all students will cover many widely separated fields in a few courses devoted to each field reduces graduate education to the level of undergraduate if not vocational study. It cannot produce the best research specialists.

Training in Industry Management

It appears that there may have been some confusion within the industry institutes as to the objective of the doctorate study since considerable emphasis in student selection before the war was placed upon the breadth of the student's interests and his extracurricular activities. The curriculum has also included a considerable amount of work devoted to special problems of industry organization and the fundamentals of management. If the industry institute requires more than three years for the award of the doctorate, the time over three years may without loss to research standards be devoted to vocational or other fields of study. However, if the objective of training the future leaders of the industry is permitted to influence the choice of students with emphasis in selection being placed upon other characteristics than scholarship, ingenuity, intellectual energy and honesty, the result will be a reduction of research attainment. It must be clearly understood that the

objective of the doctorate is the development of research scientists and engineers, not the production of managers or even leaders in any direction except research.

Benefits of Coöperation with a University

If an industry institute is located within the framework of a university or technological institute engaged in graduate study in engineering and science, many mutual benefits can be derived. The distinguished graduate teachers of the university should provide the instructional staff for most of the basic graduate courses needed by the industry's graduate students, thus maintaining much higher standards than is probable for an isolated institution. In these classes the industry's graduate students must compete with other graduate students, a procedure that maintains high educational standards and prevents vocationalization. Then, too, the influence of distinguished scientists, whose opinions cannot be ignored, will keep special courses given by the industry institute from deviating greatly from accepted graduate standards. And, finally, since the university grants the degree, the industry institute must satisfy the graduate committee and the administrative head of the graduate school of the university that proper graduate standards have been maintained.

Recommendations

It appears that industry institutes have sought high standing by restricting their programs largely to work for the doctorate when in reality the master's degree would more nearly encompass their broad objectives. The probable quality of the staff of graduate teachers at an isolated industry institute and the lack of that stimulation which should come to the student for the doctorate from association with leading scientists in many fields may restrict the meaning of the doctor's degree when given by such an institution. Until such time as a truly distinguished staff can be assembled in many fields, the isolated industry institute should restrict its graduate work to the scope of the master's degree.

(18) Considerations Applying to the Foreign Student

It appears inevitable that large numbers of foreign students will come to America for postgraduate study in technology during the decade following World War II. It seems desirable to consider the special problems that are thereby raised. In particular, it is important to realize that many foreign students are likely to offer little competency in laboratory experiment. This is because of the emphasis upon mathematics, theoretical science, and liberal studies in foreign undergraduate education even in engineering. American institutions place far greater emphasis upon work in the laboratory and upon the study of the art and practice of engineering.

Orientation and Background Study

Since the foreign student is likely to be bewildered by his surroundings and backward in speaking and writing English, as well as unversed in laboratory techniques, it would seem to be a necessary procedure in many cases to use one semester for orientation and background study to precede the work for the master's or doctor's degree. During that semester the foreign student could study English, and enroll in two or three undergraduate courses in his major field of study where em-

phasis would be placed upon laboratory experiment and practical engineering work. Among such courses might be materials testing laboratory, heat engines laboratory, and electronics or electrical machinery laboratory. Such laboratories are often unavailable to students of foreign countries. The work in these laboratories also requires less understanding of spoken English than a lecture course. By the end of one semester, it will be reasonably clear both to the student and to his adviser whether his background is adequate for graduate study.

(19) Guidance of Graduate Students

It should clearly be the objective to select students for graduate study who will accept the accompanying responsibility and who can therefore be treated as adults. However, the common suggestion to "first spend two or three years in engineering practice" is not always practical advice. Within three years a large percentage of engineering graduates have married and their financial responsibilities may preclude full time graduate study. Others are drawn into construction or production with a resultant dulling of their interests in scientific studies. Practical advice to brilliant undergraduate students is to enter the graduate school immediately after graduation before there is a loss of facility in the use of mathematics, physics, and the theoretical tools of engineering.

Counseling Graduate Students

Since graduate students are always in close contact with certain teachers, guidance occurs naturally and without formal organization. Even then, problems of a personal nature often arise such as physical disability, financial difficulty, or mental strain that are better handled by the usual university offices. The teacher will function most effectively if he directs the student to the proper office since new graduate students are nearly as uninformed as freshmen.

Graduate Class Assignments

It is a common experience to find graduate students quite unversed in the use of the library. One objective of the first semester of graduate study should be to encourage students to use the library for background reading, assigned literature searches, etc.

The treatment of graduate students as adults results occasionally in an overbalance toward failure on the part of the teacher to make specific assignments with consequent neglect of the course by the student. Undergraduate engineering education is conducted to a large extent through the assignment of homework problems. The drastic change from detailed problem assignments to no assigned problem work is too great a transition to be accomplished in a week or two.

The teacher should start his graduate course, particularly if it is for first semester graduate students, in such a manner that he can roughly measure the outside time devoted by the student to preparation. When it is clear that progress is being made by the students on their own initiative, greater freedom in study is obviously desirable. However, assigned problem work need not be dropped entirely to develop initiative. The instructor may accomplish much merely by requiring the solution of problems and by leaving their conception and statement to the student.

(20) Relative Teaching Load of Graduate and Undergraduate Courses

In 1935 the S.P.E.E. Committee on Graduate Study reported teaching loads that on the whole were not conducive to graduate instruction of high quality. The committee found that in many institutions, though not all, graduate teaching loads had been added to the existing relatively heavy loads of undergraduate instruction. It should be observed that this situation was found at a time when graduate work had been expanding very rapidly, at a pace that budgets could scarcely match. An informal check made during 1942 indicates that since 1935 some improvement had been made. In most schools the teacher giving graduate work is now relieved of some of the undergraduate teaching he would otherwise carry. The ratio of adjusted hours has sometimes been less, sometimes greater, than unity.

Universal Importance of the Problem

Proper relative weights for graduate and undergraduate teaching loads may best be decided upon after a consideration of the institutional functions as a whole. The general functions of an engineering school of high standing should include undergraduate instruction, graduate instruction, and research. The teaching staff should be selected and loads should be assigned in order to obtain a balance among these activities. Exactly what proportions of each activity constitute a balance will, of course, vary from school to school and from department to department, but that all three functions should be present in the departmental staff can scarcely be questioned. The individual staff member has only so much total time and energy and, if adequate allowance is not made for graduate work and research, they are certain to be slighted.

Factors Involved in Teaching Loads

The general problem of ascertaining the weight of the teaching load of a staff member involves numerous factors other than contact hours. Some of these factors are the size of the class, the number of different classes for which a single preparation suffices, the amount of time required outside of the class per scheduled class hour, other contributions to the work of the institution such as student conferences and committee assignments.

It is therefore recommended that all factors be analyzed before adopting any scheme for controlling faculty teaching loads. Until such a plan has been adopted, it is recommended that graduate courses and undergraduate courses be treated alike in setting teaching loads. Evidently, some provision must also be made for evaluating the equivalent teaching load involved in the direction of thesis research. It appears self-evident that the direction of each graduate student's thesis investigation during the period of his intensive research will consume at least two or three hours per week of a teacher's time which makes it fully the equivalent of a classroom teaching hour.

The Changing Character of Engineering Graduate Study

To gain perspective we must recognize the changing character of graduate study in engineering. Undergraduate curricula in engineering of fifty years ago were heavily weighted with the natural sciences and with liberal subjects. There was not a sufficient body of specialized engineering knowl-

edge or a sufficiently extensive literature to crowd a four-year program. Graduate study in engineering was not critically needed and could hardly have been differentiated from graduate study in the physical sciences except as it might have contributed a broad review of the engineering arts. Now, this has all changed. New branches of science are developing at an amazing pace within the confines of engineering. Fluid flow, heat transfer, electronics, mechanics of stress and of vibrations—these are no longer physics even when physics is broadly defined. Neither can they be defined completely as applications of physics though they use the great body of knowledge that the physicist has accumulated.

Within engineering itself we see research workers steadily developing these new branches of engineering science. This changing character of engineering, this development from a construction art to a broad productive activity encompassing research, design, and construction, and sustaining within itself the beneficent growth of whole new branches of science, is the vital force of graduate study.

The assurance which we feel that the scientific or research side of engineering will continue its growth at an accelerated rate is strong support for the belief that graduate study in engineering is destined to grow in importance. Faced with increasingly complex engineering problems that can only be solved with these new scientific tools, industry must turn to the graduate schools of engineering for her future leaders in research, design, and development. That many of these scientific leaders will then become administrators we know by observation, and intuitively we feel that specialized graduate study will still contribute much to their ultimate capacities to appraise, digest, and weigh evidence bearing on broader subjects.

To the Editor of The Journal of Engineering Education

May 9, 1945

DEAR SIR:

In the December issue of the JOURNAL OF ENGINEERING EDUCATION, I saw on pages 285 to 287 an article by Assistant Professor G. E. Bush, in which he presents the translation of a small part of a paper by Professor N. Rosenauer of Riga for finding the velocities of complex kinematic chains in a direct way.

Apparently, Professor Bush did not have available the complete paper of Professor Rosenauer, and therefore his article is very fragmentary. It would be interesting to know what article by Professor Rosenauer Professor Bush has translated, and where he obtained his reference, as the latter is not given quite accurately.

It is a general experience that readers often have difficulties in locating the original articles if references are not accurate. Since previous to Professor Bush I had drawn attention to Professor Rosenauer's work in my paper: "A Brief Account of Modern Kinematics," presented before the A.S.M.E. Annual Meeting in December, 1942, with preprints available at that time, the paper having been published finally in the A.S.M.E. Transactions, August, 1943, pp. 663–683, I may be permitted to repeat here the reference given there on page 670 under (E), namely:

"Ein neues Verfahren zur Geschwindigkeitskonstruktion kinematischer Ketten," by N. Rosenauer, *Acta Universitatis Latviensis, Mech. fac.*, serija T.L., No. 14, 1936.

Professor Rosenauer's method has also been described by him elsewhere, and I have just been informed by a Russian professor, of Moscow, U.S.S.R., that this method was described previous to Rosenauer by several Russian scientists. However, so far I have not been able to verify this statement, because none of the references cited by the Russian professor are available here in the United States. Hence, I have to suspend judgment regarding the priority of this method.

Yours very truly,

A. E. R. DE JONGE,
85 Liberty St.,
New York 6, N. Y.

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